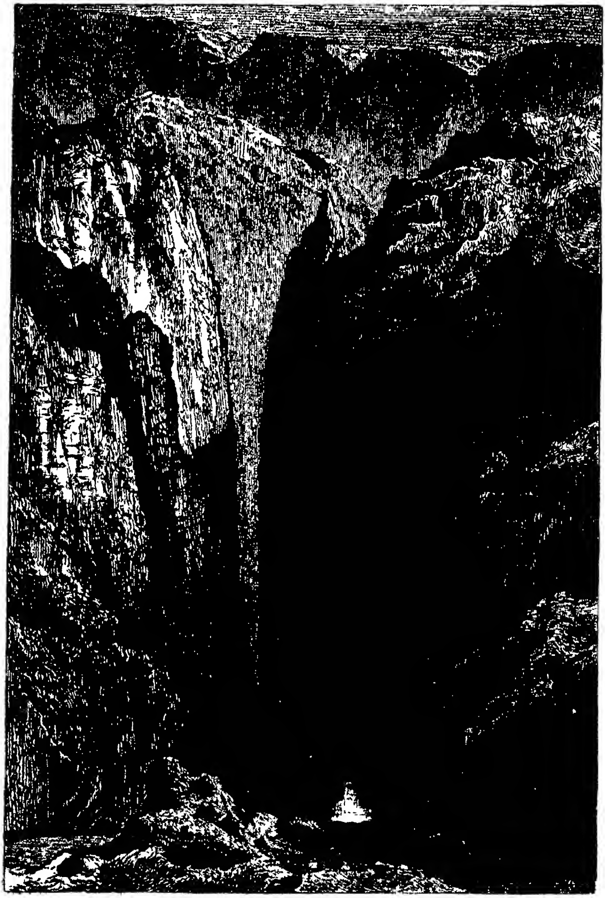
SCHOOL MANUAL OF GEOLOGY



Cañon (or Ravine) on the River Colorado, California, from the Report by Lieut. Ives: showing the power of rivers to cut down through rock.— See page 103.

THE SCHOOL MANUAL OF GEOLOGY

By J. BEETE JUKES, M.A. F.R.S.

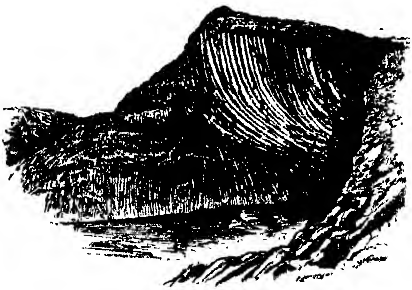
LATE DIRECTOR OF THE GEOLOGICAL SURVEY OF IRELAND, AND AUTHOR OF THE 'STUDENT'S MANUAL OF GEOLOGY,' ETC.

THIRD EDITION, REVISED AND ENLARGED

EDITED BY

ALFRED J. JUKES-BROWNE, B.A. F.G.S.

OF H.M. GEOLOGICAL SURVEY



Basalt Columns in Clam-shell Cove, Staffa.

EDINBURGH: ADAM & CHARLES BLACK

1876

Printed by R. & R. Clark, *Edinburgh.*

PREFACE TO THIRD EDITION.

IN preparing the second edition of this Elementary Manual, it was felt, as explained in the Preface, that "having regard to the great advance of Geology and its associate sciences since the first appearance of the work, it was necessary to make many additions, to re-write some parts, and to re-adjust several of the chapters." More than three years have now elapsed, and another edition is called for, requiring further extension and improvement. Before noting, however, the alterations made in the present issue, it will be desirable to restate how far the previous one was modified by giving a further extract from the Preface :—

"My endeavour has been to preserve, as far as practicable, the style and method of treatment pursued by the author, and to carry out, as completely as I could, his object in writing the

work. Thus, in Chapter V., although the explanation of Acids and Bases may not be thought quite up to the present time, the facts seemed to me more easily explained in this way than according to more recent theories.

"Several new woodcuts have been inserted, and among them a group of Lower Cambrian fossils (Fig. 37). The translations of scientific names in Part III., formerly interspersed throughout the text, have been collected into lists, and appended at the bottom of the pages on which they occur, thus allowing the names themselves to be printed in italics.

"Finally, a copious use has been made of headings to paragraphs, in order that the student may more easily follow the arrangement adopted."

In the present edition four of the same chapters which formerly required alteration, namely, Nos. V., XIII., XX., and XXIV.,—have again undergone revision.

The mineralogical arrangement of rocks recommended in the Appendix, and now so generally accepted, has been substituted for the former classification.

In Chap. XVI. another grouping of the Palæozoic formations has been adopted in preference to that formerly given, and a partial re-writing of the chapter was thus necessitated; the history of the Glacial Period in Chap. XXIV. has also been revised and amplified.

On completing this new edition of the School Manual, I desire to repeat that the labour of its preparation has been lightened by the pleasure of following my uncle's footsteps, and the sense of its being a duty and respectful tribute to his memory. I now commit to the public my further attempt to sustain the reputation and usefulness of the original work by keeping it (to the extent of my ability) in accord with the progress of the Science which its author loved so well and taught so efficiently. Although his removal deprived me of an invaluable guide and preceptor, yet the benefit of his example remains, and with this before me, I have at least spared no pains in the accomplishment of my task, and I trust that in attempting to renovate, I may not have marred, his work.

It has been my good fortune to find in the Rev. T. G. Bonney of Cambridge as kind a friend as

my uncle found in the late Professor Sedgwick; in the former Preface I had the pleasure of acknowledging the assistance he had afforded me, and I have now to thank him for the continuance of his help in the revision of several portions of the book.

A. J. JUKES-BROWNE.

CAMBRIDGE, *April* 1876.

PREFACE TO FIRST EDITION.

THIS little book is intended for the use of young persons of fourteen or fifteen years of age and upwards, who may be supposed to have a sufficient knowledge of Geography and other kindred subjects, to understand it and read it with interest. It is hoped that it will serve for the commencement of their studies in Geology. It is also offered to grown-up persons who have no time for a more extended study of the science, with the hope that they may gain from it a fair general notion of the scope and nature of that science.

The chief difficulty the learner meets with in the study of Geology, is the want of the preliminary elementary knowledge of the collateral sciences of Physics, Chemistry, Mineralogy, Zoology, and Botany. If the elements of those sciences were made part of our ordinary education, as I think

they ought to be, and as they might be without any difficulty, it would then be easy to teach their application to Geology.

Any one who was familiar with the appearance and nature of ten or a dozen of the most common and abundant Minerals, would have no difficulty in comprehending the origin of Rocks. If the pupil knew the outlines of Zoology, there would be no occasion for the teacher in Geology to spend time and labour in explaining to him that a Whale was not a Fish, nor a Bat a cross between a Mammal and a Bird, or showing him the difference in bivalve shells between a Brachiopod and a Conchifer, or between a Gasteropod and a Cephalopod in univalves, or guarding him against the supposition that a Coral was built by an Insect. If this and similar elementary knowledge were previously acquired, the teacher of Geology would feel that the common technical terms of Natural Science, which he must inevitably use, were familiar and well understood, instead of being passed over as mere scientific mysticism. The faculties also of his pupils, being already trained to the observation of some natural objects, would be prepared readily

to observe the very simple geological facts which any one may see in his daily walks. No one, who has once had his eyes opened to the real nature of the common earth and stones on which he treads, either in country roads or town pavements, can help becoming a geologist even in spite of himself.

If the perusal of the following pages impart sufficient rudimentary knowledge to excite and guide this faculty of observation, the chief object for which it was written will be attained.

J. BEETE JUKES.

DUBLIN, 1863.

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MESOZOIC OR SECONDARY EPOCH.

TERTIARY OR CAINOZOIC EPOCH.

ERRATA.

Page 223. Heading, *for* Lower Silurian, *read* Cambrian.
225. ,, ,, ,, ,,
251. ,, *for* Carboniferous, *read* Devonian.

PART I.

Geological Operations now in Action.

CHAPTER I.

OF THE EARTH AS A WHOLE.

THE Earth has been both measured and weighed, its measurement giving us its form as well as its size.

The Form and Size of the Earth.—The figure of the Earth is not that of a perfect sphere, but one that is called an *oblate spheroid.* By this phrase we mean that the polar axis, or imaginary line about which the Earth revolves, is its shortest diameter, and that as we recede from the Poles, or ends of that axis, the diameters of the Earth are longer and longer, till we come to the Equator, where they are longest.

The length of the polar diameter is 7899·17 English statute miles, and that of an equatorial diameter is 7925·65 of those miles. A line passing through the centre of the Earth, then, from any point on the Equator to its opposite is almost exactly 26·5 miles longer than the line which passes through the centre from Pole to Pole.

B

Let the diagram, Fig. 1, represent a section of the Earth through the centre *c*, the line P P being its axis of rotation or polar diameter, and the line E E an equatorial diameter. If the Earth had been a true sphere

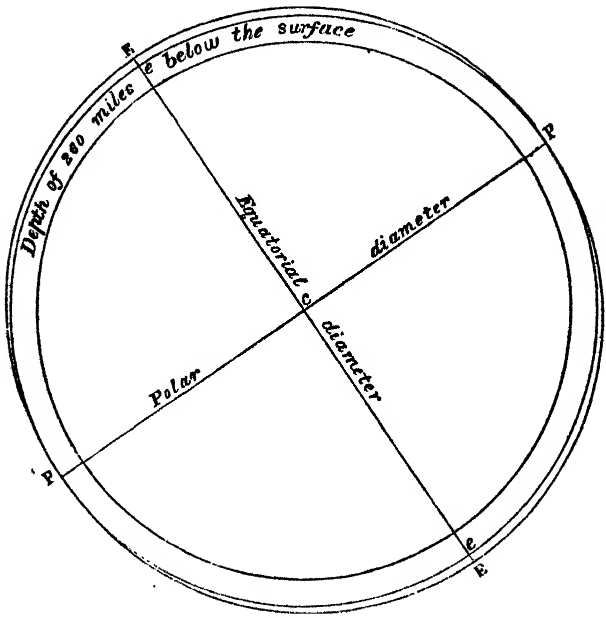


Fig. 1.
Section of the Earth.

these two lines would of course have been exactly equal, and if we had turned the line P P on the centre *c* till it lay upon E E, the points P P would have exactly coincided with the points E E. But as the line P P is

in reality 26½ miles shorter than the line E E, it is obvious that the points P P would fall short of the points E E by a space equal to half that distance (*i.e.* by 13¼ miles) on each side. Let us suppose that they would only reach to *e e*, then the two little spaces between *e* and E on each side would represent the amount of the bulging of the equatorial parts of the Earth's surface beyond the shape of a true sphere.

In the figure, however, the distance between *e* and E is greatly exaggerated in order to make it distinct. The line P P is a little more than three inches long, being drawn on a scale of 2600 miles to one inch to represent the distance of 7899 miles. A space of 1-10th of an inch has been taken inside P P, on which, from the centre *c*, to strike the inner circle seen in the figure; this space will of course represent 260 miles, a tenth of that space would represent 26 miles, and that tenth would require to be again divided in half to represent 13 miles. The distance between *e* and E, then, should be only 1-20th part of the space between P and the inner circle, which would not be more than the width of one of the lines in the figure.

Making allowance for this necessary distortion, we may take the outer curved line P E P E as representing the true surface of the Earth, and the circle P *e* P *e* as the surface of an imaginary sphere drawn on the polar diameter, which sphere would coincide with the actual surface of the Earth just about the Poles, but sink beneath it gradually from the Poles towards the Equator. The depth of this imaginary true

sphere, below the actual surface, will be $13\frac{1}{4}$ miles at the Equator. Now, $13\frac{1}{4}$ statute miles make 69,960 feet, or, in round numbers, 70,000. The equatorial parts of the Earth, then, bulge to an amount of 70,000 feet beyond the form of this true sphere. We might liken this protuberance to a vast mountain 70,000 feet high under the Equator, with sides sloping regularly down towards the Poles.

Now it is probable that the bed of the ocean is nowhere so deep as 70,000 feet; and that the hollow in which it lies is entirely within the protuberance thus described, and nowhere reaches the imaginary internal sphere except in the polar regions, where, however, the sea does not appear to be nearly so deep as in lower latitudes. The irregularities of the surface which rise above the level of the sea and form the dry land are still more insignificant. The mountains are mere pinnacles, the highest being Mount Everest, in the Himmalayahs, which is 29,000 feet above the sea. The table-lands are not extensive; that of Thibet, forming the greatest bulk of high land, is from 400 to 600 miles across, with an altitude varying from 11,000 to about 15,000 feet above the sea. These irregularities, then, are obviously small when compared with the protuberant shell of the globe, and are in fact mere irregularities in that shell. They become of infinitesimally small account when we recollect that the protuberant shell itself would be represented in Fig. 1 by merely doubling the thickness of one of its lines.

Small, however, as is this protuberant mass when

compared with the whole bulk of the globe, its existence involves important consequences.

The first of these consequences is the stability of the Earth's axis. Ever since the Earth first acquired this figure, it is very difficult even to imagine any impulse sufficient to make the Earth revolve upon any other axis than this of its shortest diameter, or anything so to affect the form of the Earth as to cause any other diameter to become shorter than the one which was originally the shortest.

The second consequence is that this figure, being very nearly the precise form which the globe would have assumed had it been originally a pasty or fluid mass revolving with its present velocity, naturally induces us to believe that it once was in that condition. If a ball of molten matter were set to spin round one of its diameters, it would naturally tend to bulge about the parts farthest from that diameter, the bulging being great in proportion to the velocity of its rotation, until the greater distance of those parts, and the consequent greater space they travelled in each revolution, produced a balance between the centrifugal force of the rotation and the centripetal force due to the attraction of gravity in the mass. The fact that the Earth has this protuberant form is strong evidence in support of the conclusion that it actually did thus adjust its shape to the impulse of its motion, and that therefore it was at one time sufficiently plastic to admit of this adjustment; in short, that it was either in a fluid or at least in a pasty condition.

Internal Condition of the Earth.—This original plasticity in the matter of the globe, though it is by no means to be taken as a certainty, may yet be accepted as a probability, agreeing very well with some other known facts, which are in favour of the idea that if the matter of the Earth were originally plastic it was so in consequence of its own heat being sufficient to keep its substance in a molten or semi-molten state. Should future research, however, lead our ideas in a contrary direction, or even prove this conclusion to be entirely erroneous, it would make little difference to the science of Geology, which does not concern itself much with any possible former condition of the globe very different from the present one.

Without then further considering the question as to whether the entire Earth was originally in a molten state or not, the following facts tend to show that in all probability its internal portion has for a long time possessed a high temperature of its own, independently of any heat derived from the Sun or other external source.

a. *Temperature of Deep Mines and Wells.*—Direct observation on the temperature of the interior of the Earth, so far as we are able to descend into it, shows that the summer heat or winter's cold does not penetrate far, so that at a depth not exceeding 100 feet in any part of the globe a thermometer would mark the same temperature all the year round.

Below that "*stratum of invariable temperature,*" the rocks get warmer the lower we descend. Obser-

vations have been made in mines in many parts of the world, with every precaution against mistake, but the same result has always been arrived at. In our own country, Mr. Henwood found, as the result of his experiments on the temperature of the slate rocks, in 200 mines in the counties of Cornwall and Devon, that at 300 feet they were about 57° F., at 600 feet about 62° F., at 900 feet about 68° F., and at 1200 feet about 78° F. He states, however, that in the granite rocks the temperatures were not quite so high.

In the coal mine at Monkwearmouth, Durham, at a depth of 1600 feet the temperature ranges from 78° to 80°, or constant summer heat. At the bottom of the deepest coal shaft in Britain, that of Dukinfield, near Manchester, which is 2151 feet deep, the temperature is constantly 75° F.

While then there is considerable variation in the amount of the increase of temperature, and in the rate of increase at different places, the fact remains undoubted that, without any exception, the heat always does increase after passing below the first hundred feet, and it appears that the average rate of this increase may be taken at about 1° F. for every 60 feet of depth beyond the first hundred.

The temperature of the water in very deep wells is in accordance with these results. The Artesian well of Grenelle, near Paris, was bored to a depth of about 1800 feet, with the expectation of not only finding water, but of getting it always of a uniform and rather high temperature, and it has a constant temperature of

nearly 82° F., which is about 22° hotter than the mean temperature of the ground beneath Paris, as observed in the cellar of the Observatory there. Similar results have always been found to attend the rise of water from other very deep Artesian wells.

b. Hot Springs.—The numerous hot springs which flow out to the surface of so many parts of the earth may be divided into two classes—those in volcanic districts, and those not in volcanic districts. The latter usually occur where geologists can show that there are great fractures in the rocks, of a kind which they call "faults," those fractures proceeding from a great depth; and this renders it probable that the hot water travels from a great depth up these fissures, and is hot in consequence of the depth from which it comes.

c. Igneous Rocks.—The numerous volcanic orifices which are scattered here and there all over the Earth, and from which molten rock is so often belched forth in large quantities, give us also a proof of a widely spread source of intense heat existing everywhere beneath the surface. But the lavas derived from existing volcanoes form only a small part of the igneous rocks which are found in the crust of the Earth, all of which have certainly come from the interior.

d. Specific Gravity of the Earth.—The specific gravity of a substance is its weight compared with that of the same bulk of pure distilled water at a temperature of 60° F. The specific gravity of the Earth has been determined by two or three independent methods, the results varying from about 5 to about 6½. We may

then safely conclude that the Earth is about five or six times as heavy as it would be if it were all pure uncompressed water. Now most stones and rocks vary in their specific gravity from about 2½ to 3. The Earth, therefore, is about twice as heavy as it would be if it were made entirely of such rocks as those that we see at the surface, and those rocks were uncompressed. We know, however, from the nature of the attraction of gravitation, that the same materials at the same temperature would necessarily be much denser in the interior of the Earth than they are at the surface. Professor Leslie formerly stated that at a depth of 34 miles, air would be as heavy as water, and water at 362 miles as heavy as mercury. It is also stated that at the centre of the globe cold steel would be compressed into a fourth of its bulk, and most stone into an eighth. Astronomers tell us that the Earth is certainly not a hollow body, and that it does become continually denser to the very centre (see Herschel's *Physical Geography*, p. 7). It seems certain, therefore, that it must have had a specific gravity of more than twice that of ordinary surface rock, unless some expansive force resided in the interior, able to resist the condensing force of gravitation. But the only expanding force we know of that is capable of this is Heat.

Conclusions.—Putting all the preceding considerations together, we can hardly avoid arriving at the conclusion that the interior of the earth is intensely hot.

If we were to suppose that the increase of temperature went on at the same rate indefinitely into the

interior as that which regulates it in our mines and wells, or even if we allowed that it increased at a slower rate—say, for instance, 1° F. for every 100 feet of descent, or nearly 53° F. for every mile, and assuming the temperature of the invariable stratum beneath the British Isles to be 50° F., we should arrive very shortly at an intense temperature. At a depth of about three miles beneath these Islands the rocks would be as hot as boiling water, or 212° F.; at a depth of 50 miles we should find a temperature of nearly 2700° F., or a heat sufficient to melt steel; and at 100 miles, or less than half the space between the outer and inner circle in Fig. 1, we should get a temperature equal to more than 5000° F., which is a heat greater than any that we know at the surface.

It is not by any means necessary, however, to suppose that the temperature does increase indefinitely into the interior, or that the rate which regulates its increase near the surface continues to be the same for such depths as these mentioned above. Neither does it follow that the materials, whatever they may be, which exist at great depths, would be melted by the same amount of heat that would fuse them at the surface, since the enormous amount of pressure which they must experience may keep them solid in spite of the heat.

Little or nothing is in fact known about the constitution or condition of the interior, nor have we any grounds even for speculation, further than those which have been previously mentioned.

CHAPTER II.

VOLCANOES.

If the Earth be really a globe of intensely heated and perhaps molten matter, with a cooled crust of uncertain but perhaps not a very great thickness, we might not unreasonably expect that external symptoms of its internal condition would occasionally be made manifest. As a matter of fact we know that incandescent earthy matters are frequently ejected from the interior through holes in the crust, and that movements of greater or less violence are occasionally felt through large parts of that crust, evidently proceeding from some disturbing force within it.

Form and Structure of Volcanoes.—A volcanic mountain consists of a conical pile of cinders and ashes heaped up round a central orifice, from which they have been violently ejected into the air, so as to fall on all sides round it. A strong wind blowing at the time sometimes causes a greater accumulation on one side than on the other. The finer and more impalpable powder is sometimes ejected to such a height as to be carried by the winds for many miles, even sometimes several hundred miles, from the orifice, and to fall eventually over a very wide space, into the sea as well

as on to the land. Great blocks of molten lava, called volcanic bombs, are often shot up, and fall near to the mountain. Floods of lava now and then boil up, and either break through the sides of the pile of cinders and ashes or flow over the lip of the *crater*,* as the mouth of the central funnel is called, and roll down into the adjacent country.

Successive eruptions often take place from the same vent, but other lateral orifices are sometimes opened close by, and minor eruptions proceed from them. The lesser cones and craters thus produced are often subsequently buried under the accumulations derived from the more dominant ones. Series of cones are frequently arranged along nearly straight lines, as if over great linear fissures in the earth's crust.

If we were to cut open a line of volcanic cones we should probably find their structure to be similar to that suggested by the diagram in Fig. 2, in which the

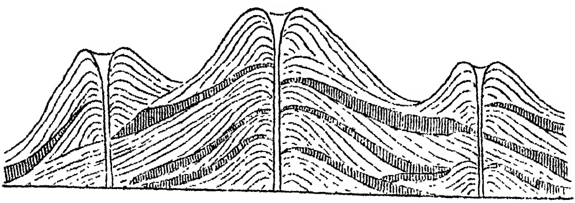


Fig. 2.
Ideal Section of Volcanoes.

parts shaded by vertical lines are intended to represent lava-streams, and the other parts to show the different

* From the Greek word for a goblet.

irregular layers of ashes and cinders, of which the cones are made up.

In addition to these, however, the internal parts of volcanoes would be found to be traversed by *veins* of lava of greater or less magnitude, sometimes running between the beds of other materials, and at others cutting across them, or even cutting through other veins that had been previously formed. Fig. 3, which is taken from a rough sketch made from the deck of H.M.S. Fly, of some veins of lava seen in the cliffs of the south side of the Island of Madeira, will serve to give a notion of these veins of injected material.

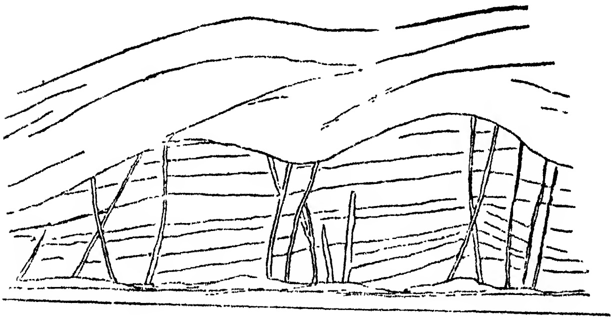


Fig. 3.
Veins or Dykes of lava in the Cliffs of Madeira

It will be easily understood that when molten lava is being forced up in the inside of a volcanic mountain, some of it may be injected in a liquid state into any crevices or cracks which may have previously existed, or may be caused by the internal impelling force.

These veins, or *dykes* as geologists call them, when they are cooled, form heavy solid stone, and serve to tie or brace together and support the looser and more incoherent portions of the mountain.

Examples of Volcanoes.—The quantity of materials ejected from the interior of the Earth on to its surface is sometimes very great, as the following instances will show.

Etna.—The volcanic cone of Etna stands on a base which is 30 miles across, or the size of a small English county, and its summit rises, with a very gentle average slope, to a height of nearly 11,000 feet above the sea. If we were to put Snowdon, the highest mountain in Wales, on the top of Ben Nevis, the highest in Scotland, and Carrantuohill, the highest in Ireland, on the summit of both, we should make a mountain but a very little higher than Etna, and we should require to heap up a great number of other mountains round the flanks of our new one in order to build a gentle sloping pile which should equal Etna in bulk. Some of the lava-streams on the present surface of the mountain are from 20 to 30 miles long, one or two miles in width, and from 100 to 200 feet deep. The valleys and ravines show other similar lava-streams beneath the surface, separated from each other by beds of ash, or "tuff," as the ejected fragmentary materials are called. There is one valley, called the Val del Bove, on the eastern flank of the mountain, which is four or five miles in diameter, and encircled by magnificent precipices, some of which are 3000 feet high, and expose the structure of that part of the mountain in a

wonderful way. Vesuvius, which is only 3922 feet high, could then be almost hidden away in this valley, which has been formed on one flank of Etna. It is well worthy of remark that Etna had arrived at very nearly its present size and altitude 2500 years ago, when it was described by the early Greek poets. The lava-stream which stopped the Carthaginians in their march against Syracuse, 396 years before Christ, may still be seen at the surface, other and older lava-streams appearing underneath it. (See Daubeny's *Volcanoes* and Lyell's *Principles of Geology*.)

No fewer than 600 minor cones show their heads round the flanks of Etna, some of them as much as 700 feet high and two miles in circumference, and many others are now more or less buried under subsequent accumulations.

Vesuvius.—This mountain, so small in comparison with Etna, has had a proportionately larger increase since the year 79 A.D., which is the date of its first eruption during the historical period. The main outer bulk of the mountain, however, had been formed long before; the old summit of its curved ridge being now known as the Monte Somma, and it is within the old ruined crater, partially encircled by that ridge, that the modern cone has grown since the year 79. Nothing like an eruption is spoken of by any Roman author before the days of Pliny, so that this volcanic focus must have lain dormant for at least 800 years, and then suddenly burst into activity and remained active ever since, with the exception of one or two pauses of one or two centuries each in length.

The neighbouring volcanic Island of Ischia had an eruption during one of these intervals in the year 1302 A.D., after it had been dormant for at least 1400 years.

The history of all volcanoes shows us that long periods of rest usually elapse between those great eruptions which contribute in any sensible degree to the bulk of the mountains.

Iceland.—The Island of Iceland, which is about as far from Cape Wrath, in Sutherlandshire, as that is from London (rather less than 600 miles), is entirely composed of volcanic materials. It is considerably larger than Ireland, and has more than twenty volcanic mountains from which eruptions have been recorded. Snaefell is believed to be its loftiest summit, reaching to 6860 feet above the sea; but Hecla (4900 feet) is the best known, as the one from which the most frequent eruptions have taken place. Some of the Icelandic eruptions have caused vast floods of water, since they melted the snows and let loose the glaciers which perpetually clothe the highest parts of the island, and these floods have torn great ravines in the sides of the mountains, and carried down large rocks and heaps of smaller fragments on to the lower lands, and have even added sometimes miles of new land to the coast line of the island. (See Poulett Scrope's *Volcanoes*, p. 409; Edition of 1862.)

The most tremendous eruption on record in Iceland was that from Skaptar Yokul, in the year 1783, which was especially remarkable for the immense floods of lava that were poured forth. One of these lava-streams

was 50 miles long and 15 wide in some places; and another 40 miles long, with an occasional width of 7 miles; each of them having an average depth of 100 feet, increasing here and there to 500 or 600.

Had such an eruption burst from a mountain over Oxford, for instance, one of these streams might have filled up the valley of the Thames as far as London, while the other would have extended to Gloucester.

If we imagine the eruption to have taken place from Lugnaquilla in Wicklow, one stream might have filled up the valley of the Liffey down to Dublin Bay, while the other obliterated the valley of the Slaney as far as Wexford Harbour.

Or lastly, if we suppose it to have broken out about Dollar Law in Peeblesshire, one stream might have filled the Valley of the Tweed, and the other that of the Clyde, reaching to the neighbourhood of Berwick and Glasgow respectively.

Tomboro in Sumbawa.—The grandest eruption perhaps of which we have any published description, was that which occurred in the year 1815 in the Island of Sumbawa—one of that chain of islands that stretches due east of Java towards New Guinea. The mountain called Tomboro in that island burst into an eruption on April 5th, which was most violent on the 11th and 12th, and did not entirely cease till July. The sound of the explosions was heard in Sumatra, 970 miles to the westward, and in Ternate, 720 miles towards the east. Great tracts of land were covered by lava, several streams of which rolled into the sea. Floating

cinders were met with on the sea to the westward of Sumbawa, forming a mass several miles in extent and two feet thick, so that vessels with difficulty forced their way through them. Stones from the size of walnuts to that of a man's head fell in showers on all the country near the volcano. The ash or light impalpable powder was ejected in such immense profusion as to cause a darkness more profound than that of the blackest night, even in Java, the nearest part of which is 300 miles west of the volcano, and that for a space of three days. Some of this ash fell in Amboyna and Banda, which are about 800 miles east of the volcano, although it was during the season of the eastern monsoon, showing that this ash was ejected through the lower currents into the upper regions of the atmosphere, where the counter-currents prevail.

Some evidences of this eruption were perceptible during its occurrence over an area which had a circumference 1000 miles distant from the volcano.

Supposing then that it had broken out from a volcano in the situation of Mont Blanc, it might have been heard or felt at once in the Hebrides and in Greece, or in Morocco and in Poland, while all the country from Paris to Florence, and from Munich to Barcelona, would have been kept in utter darkness for one or two days in consequence of the falling ash.

Nicaragua.—The volcano of Coseguina in Nicaragua had an eruption in 1835, the roaring of which was heard in Jamaica, 800 miles north-east of the volcano, and the sun was darkened by the ashes that fell there,

which must have been carried by the upper current and fallen back through the north-east trade wind. H.M.S. Conway was at the same time covered with ash while sailing in the Pacific 700 miles south-west of Coseguina.

The instances of volcanic action mentioned above are a few, selected for the purpose of giving an idea of its power and results. In Sir C. Lyell's *Principles of Geology*, in Dr. Daubeny's and Mr. Poulett Scrope's works on *Volcanoes*, many more detailed accounts will be found, which the limits of this little book do not allow me to extract.*

Dormant and Extinct Volcanoes.—The history of Vesuvius shows us that volcanoes may remain dormant for several centuries, and then burst again into activity. Some volcanoes, the lava-streams and ashes of which look recent, but which, like Ascension Island, have had no eruption since the period when they have become known to civilised man, may be thus dormant. Others again, like those of the Puy de Dome in central France, although still preserving their cones and craters, and having their lava-streams still rough and bristling, have not only remained quiescent during historic times, or for the last 2000 years, but probably for much longer periods. These we may call extinct volcanoes. This term may be applied with still greater certainty to others in central France, such as those of the Mont

* A compendious and inexpensive book, entitled *Earthquakes and Volcanoes*, by Mungo Ponton (Nelson and Sons), gives a very fair account of their history, phenomena, and probable causes.

Dor and Cantal, and in other parts of the world, the cones and craters of which are more or less nearly obliterated by rain and atmospheric action, and their lava-streams and ashes trenched by deep and wide valleys, so that the lava-streams which originally ran down the lowest ground they could find, are now left as cappings on the hills.

Those again lead us to districts in which all traces of the old cones are completely removed, and mere plateaux of lava (basalt) and ash spread over districts like those of Antrim in Ireland or large parts of central India and other places.

Distribution of Volcanoes.—If we look solely to active, dormant, and extinct volcanoes, properly so called —leaving the mere basaltic plateaux aside—and mark on a map or globe every spot where such volcanoes are to be found, they will be seen to be irregularly, but almost universally, distributed over the whole of it. All the oceans are spotted with volcanic islands, and groups and lines of them run through all the Asiatic islands down all the western shores of the two Americas, through all the south of Europe, and far into central Asia, if not completely across it from Asia Minor to Pekin. They are to be found in every latitude from that of Jan Meyen Island, 72° N., between the North Cape and Greenland, to that of Mounts Erebus and Terror in 77° S., and it is hardly possible to draw a meridian of longitude which will not in some part of its course cut through a volcanic area. It would be well here to consult a map of the distribution of volcanoes, such as that

in Johnston's *Physical Atlas*, or in Mr. Scrope's work on *Volcanoes*.

It is very remarkable that, with the exception of those of central Asia, almost all active volcanoes are either on islands or in the immediate neighbourhood of the sea. Africa is the only continental space where no volcanoes of any kind are known. The north of Europe and Asia, the central and eastern parts of North and South America, and the northern and central parts of Australia, appear to be quite free from them.

While, then, their general distribution round the globe shows that volcanoes are the external symptoms of some internal condition which is common to the whole globe, their being nearly confined to the neighbourhood of the larger water areas raises a suspicion that water may possibly be in some way the exciting agent which sets them into activity. Steam at a high temperature and great pressure may perhaps be the power which pumps up the fiery floods and blows out the vast clouds of ashes and great piles of cinders into the air. All rocks are more or less permeable by water, and are traversed by cracks and fissures; by these means water may get access to the interior of the earth, though how deep it penetrates, and in what way the reservoirs of steam are accumulated till they overcome the resistance of the earth's crust above them, are details about which we must as yet be content to confess our ignorance.

Time required for the formation of existing Volcanoes.—We see from the most ancient descriptions

of Etna that the additions which have been made to the bulk of the mountain during the last 2500 years are very insignificant compared with the mass that had been previously accumulated. We learn from the history of Vesuvius and other Italian and Grecian volcanoes that great intervals of quiescence often occur between those eruptions which alone do anything to increase the bulk of the mountains.

All the knowledge we possess of all other volcanoes all over the world shows that in these respects Etna and Vesuvius are not exceptions to, but examples of, the rules which regulate the formation of volcanic mountains. All volcanic mountains are apparently formed by small partial additions of matter ejected from the interior and added to the exterior from time to time. The intervals between these times are often scores of years, or even centuries, and it appears that the length of these intervals is great in proportion to the bulk of matter added at any one time. Great eruptions, during which vast ejections take place, occur rarely. A mountain that is frequently or constantly in activity does not eject any great amount of either lava or ash in any short period of time. It must therefore have required an enormous lapse of time, not merely many thousands, but many tens, or even hundreds of thousands of years for the gradual accumulation of great volcanic piles, such as Etna, and the many other still larger and loftier volcanic cones which rise from the districts just now alluded to, on all sides of the globe. Yet, in the beds on which part of Etna rests, there are

sea-shells of the same species as those which now inhabit the Mediterranean; thus, the mode of formation of the great volcanic cone, which has been reared over those buried remains, gives to still-existing species an antiquity of enormous duration.

Ancient Volcanic Action.—If we take into account extinct volcanoes, and the still older lavas to be described in Chap. V., we find that there is probably no great region of the earth's surface where volcanic activity has not at some time or other been manifested. So far as geological evidence can guide us, we have no reason to believe that there has ever been any epoch in the earth's history when volcanic action has not been displayed; it has shifted from place to place, but has never ceased to show itself. Neither have we any geological data, whatever physical evidence there may be, for the conclusion that there has been any diminution in the activity of the volcanic forces as we approach more modern times. The great eruption from Skaptar Yokul in 1783 was probably as extensive and as destructive as any of which we have evidence in early geological times.

CHAPTER III.

EARTHQUAKES.

Connection between Volcanoes and Earthquakes.—Before the bursting out of any great volcanic eruption it almost invariably happens that the neighbourhood is shaken by Earthquakes, as if by the struggles of the volcanic force to find a vent.

It has also been observed that a succession of Earthquakes in one district has been closed by a great volcanic eruption in some neighbouring district.

When the wreath of smoke disappears from the summits of Tungaragua and Cotopaxi in the Andes, the inhabitants expect Earthquakes.

During the great Earthquakes of Calabria in February 1783, the little volcanic cone of Stromboli ceased for the first time in the memory of man to show signs of activity. In 1797 the volcano of Pasto in the Andes emitted a dense column of black smoke, which suddenly ceased on 1st February, and immediately the city of Riobamba was destroyed by an Earthquake, in which 40,000 persons perished (Daubeny, chapter xxxiii.)

Mr. Mallet, in his *British Association Catalogue of Earthquakes*, gives a map of the world, in which the

districts known to have been shaken by Earthquakes are coloured brown, the tint being darker and darker in proportion to the frequency and intensity of the Earthquakes known to have occurred. The darkest colours run along the ranges of mountains on which volcanic cones occur. No very darkly coloured district is entirely free from volcanoes, and no volcano is without the dark colour except two or three, which, like those of Mount Terror and Mount Erebus in the Antarctic regions, occur in places of which we have no history, and only the bare knowledge of the fact that volcanoes exist.

Frequency of Earthquakes.—Mr. Mallet's catalogue of all the recorded Earthquakes extends from 1606 years before Christ down to A.D. 1842, and another has been made by M. Perrey of Dijon, which comes down to A.D. 1850. In these 3456 years there have taken place 6831 Earthquakes, of which records have been kept sufficient to enter into the catalogue. But of these, 3240, or nearly one-half, took place between A.D. 1800 and 1850, so that if we had had records for the whole time as nearly complete as we have for those 50 years, the number during the last 3450 years would probably have exceeded 200,000. Even during these 50 years many Earthquakes took place beneath the great Oceans, and in other parts of the Earth where they were not felt by civilised man, and therefore no record of them was kept. It is only, in fact, within this century that our accounts from the remoter parts of the Earth have been sufficiently frequent to

enable us to know when an Earthquake did take place in them.

Even if we confine our attention to the great Earthquakes we arrive at similar conclusions. Mr. Mallet considers an Earthquake a great one which is felt over an area of 1000 or 1200 miles in diameter. If it is only felt over a space 400 miles wide he places it in the second class, and in the third if it is not felt over a greater space than 100 or 150 miles. Now of *great* Earthquakes there are 216 recorded in the catalogue, but 53, or nearly one-quarter of these, occurred within the 50 years above mentioned.

It appears from these accounts that there is on an average at least one *great* Earthquake every year in some part or other of the world. But if we include all Earthquakes of sufficient importance to be recorded, it would appear that there are two every week. During the last four years of Mr. Mallet's catalogue, from 1839 to 1842, he records 406 Earthquakes. We may very reasonably conclude that the reason why the number in these years was greater than in any previous years was, not that there were more Earthquakes, but that they were more carefully and frequently recorded. Still many may have happened that were not known to us, because there was nobody in the districts where they occurred capable of making a record of them. We may therefore feel ourselves justified in arriving at the conclusion that the Earth is, in some part or other of its surface, continually feeling the jarring motions and vibrations caused by some force in its interior.

This force is doubtless that of the great internal heat reacting in some way or other on the cooler outer crust.

Phenomena of Earthquakes.—Mr. Mallet in the discussion of his catalogue, and his great work on the *First Principles of Observational Seismology*, published under the auspices of the Royal Society, describes an Earthquake as a wave or succession of waves traversing the crust of the Earth with immense rapidity. The actual "velocity of the shock," or movement of the ground at one spot, is very slow compared with the "velocity of transit" of the wave through the country, which is about half as rapid as the movement of a cannon shot, while the up-and-down movement of the ground is not quicker than that of a man jumping. This wave is transmitted from a subterranean region, which Mr. Mallet treats as a focal cavity or rent, and it proceeds from that focus with equal velocity in every direction. The wave reaches the surface directly over the "focal cavity" in a vertical direction, along a line which Mr. Mallet calls the "seismic vertical," and of course strikes the surface more and more obliquely as we recede from that line, and with less and less force, till it gradually fades away. By observing the direction of fissures in buildings, and other indications, Mr. Mallet shows how it is possible to determine the direction and the angle of emergence of the wave path, and thus to calculate the position and depth of the "focal cavity" from which the wave proceeded. In his book before mentioned he shows the application of these rules to

the Earthquake in Calabria in 1857, and arrives at the conclusion that the focal cavity or rent of that Earthquake was beneath a district near the village of Caggian, about 60 miles E.S.E. of Naples, its dimensions being about 9 miles horizontal and 3 miles vertical, and its centre about 5¾ geographical miles, or 35,000 feet, below the surface. He calculates that the amount of the undulation of the surface was not greater than 3 or 4 inches, with a velocity of 12 feet per second, but that it travelled across the country at a rate varying from 700 to 1000 feet per second, according to the nature and form of the ground.

Effects of Earthquakes.—Volumes might be filled with details of the different effects of Earthquakes. Sir C. Lyell's *Principles of Geology*, Dr. Daubeny's *Volcanoes*, and Mr. Mallet's various papers, contain the most striking accounts.

In the Earthquakes of Calabria in 1783 the pavements of some of the towns were thrown into the air, and found afterwards lying bottom upwards ; the foundations of buildings and the brick lining of wells were partially ejected out of the ground. Long undulating fissures were formed, some of which remained open, some closed gradually, and some suddenly. Circular openings and radiating cracks also were produced.

It is a frequent occurrence for great masses of earth and rock to slide from the cliffs and from steep banks, and these great land-slips sometimes dam up rivers and cause subsequent floods.

When Earthquakes originate beneath the sea, the

undulation of the coast is usually succeeded by a great wave of the sea, which rolls in upon the land and sweeps off all loose matters within its reach.

The great Earthquake of Lisbon happened on November 1st, 1755. It seems to have originated under the ocean, a little to the westward of Lisbon, so that the wave heaved the ground obliquely, and upset the houses as if they had been built of cards. It was felt more or less over all Spain, in Algiers, in Switzerland, Germany, France, England, Ireland, Scotland, Denmark, Norway, and Iceland, both by tremblings of the earth and by movements in the waters of lakes, rivers, and seas. In ten hours afterwards, the sea around many of the West Indian Islands was greatly disturbed, rising and falling several feet for some hours. Lesser shocks were felt frequently in Portugal, Spain, and Italy, and the North of Africa, throughout that month and the next; and some considerable Earthquakes also took place in North America, in Massachusetts, and New Hampshire. Shocks occurred frequently in or near the same area for several following years.

The Earthquake which converted Caraccas into a heap of ruins, and convulsed all the neighbouring part of South America, happened on March 26th, 1812. It was accompanied by a noise louder than thunder. The earth at Caraccas appeared like the surface of a boiling liquid. The shocks were more violent among the high Cordilleras than in the plains. They lasted for many days, and on April 5th the undulations of the ground lasted for many hours. At last, on April 24th, the vol-

cano of St. Vincent burst into eruption for the first time for nearly a hundred years, and the noise of it was heard at Caraccas, nearly 500 miles off, being conveyed, as Humboldt supposed, through the ground. The movements in South America then ceased.

In the great Earthquake of Riobamba, on February 4th, 1797, the velocity of the shock was so great that Humboldt says the "explosive movement was such as is produced by the firing of a mine, and the bodies of several of the inhabitants were thrown upon the hill of La Cullca, which rises on the other side of the Lican torrent." The actual range of vertical projection of these bodies has been calculated, according to Mr. Mallet, at 100 feet, which he says would give a velocity of shock equal to 80 feet per second.

Violent Earthquakes have occurred during the present century in Mexico, in the basin of the Mississippi, in India, in New Zealand, and many other parts of the world, all characterised by the same phenomena.

Our own Islands are occasionally affected, not only by the vibration from remoter sources, but by Earthquakes of their own, as that of November 1848, which shook part of Ireland and England.

At Comrie in Perthshire slight shocks have been repeatedly felt for several years, accompanied sometimes by the usual noises, like distant artillery, etc., and appearing to run in a north-east and south-west direction.

Power of Earthquake Force.—Mr. Mallet assigns $30\frac{1}{2}$ geographical miles, or 185,000 feet, as the limit of

depth at which any Earthquake originates. Whatever may be the depth of the impulse, however, we are compelled to attribute to it an almost inconceivable power, when we find it producing such effects as those just mentioned, over so large a portion of the Earth's surface. A force that can heave a mass of rock many miles thick, and send an undulation, or even a sensible vibration through it, that shall be felt for 500 or 600 miles around, must needs be one of which we can form no adequate conception. Its disturbing effect fades away as we recede from its centre of origin, both upwards and sideways; so that, terrible as may be the shocks felt at the surface, and destructive as they may be there to human buildings, or even to the rocks themselves, they must be feeble compared with those produced in the immediate neighbourhood of the originating impulse. The surface is protected from the full force of the disturbing agent by the thick shield of the Earth's crust; the dent, so to speak, on the part of that shield which first receives the blow, must be much more marked than anything produced by the vibration on its outer surface. The surface phenomena of Earthquakes, then, may be looked upon as merely slight indications of the amount of disturbance taking place below.

CHAPTER IV.

RISE AND FALL OF GROUND.

We are so accustomed to see the waters of the ocean rise and fall with the tide, or in waves under the influence of the wind, that if we find proof that a part of the dry land was once under the sea, our first natural conclusion is that the sea has sunk in its bed. In like manner, if we find any part now covered by the sea which we know was once dry land, we are more apt to suppose that the level of the sea has risen, than that the solid land has been depressed.

A little reflection, however, will show us that the mean level of the upper surface of the ocean must be one of the most unalterable things in the world. By the mean level is meant that level which the ocean would have if it were at perfect rest, and there were no such things as winds, or tides, or earthquakes.

Suppose we have a basin full of water up to a certain mark, and we propose to raise the surface of the water above that mark, we must either add more water or we must lessen the capacity of the hollow in which it lies. To do the latter, we must either suppose the walls of the basin compressible and squeeze

in the lower part of it, or we must put some other solids into the basin.

In like manner, if we wish to bring down the level of the water in the basin below the mark, we must either take some of the water out of it, or we must enlarge the hollow in which it lies.

So long as the quantity of water remains the same, then, we can only permanently raise or lower the level of its surface by altering the shape and capacity of the basin in which it lies; in other words, to effect a permanent change in the surface of the fluid, we must alter the form or position of the solid which contains it.

This is equally true whether the basin spoken of be a slop-basin on a tea-table, a pond in a garden, a lake, a sea, or the ocean.

If, then, we can show that any change has taken place in the relative level of land and sea, we may feel sure that it is the land which has moved, and not the sea, unless we resort to the highly improbable supposition that a sufficiently large quantity of water has been bodily added to, or removed from, the earth, to produce the effect.

Even if that had taken place, it is clear that the permanent rise and fall of the water must have been equal all over the globe, for there is but one great ocean, of which such inland seas as the Mediterranean, and Black Sea, and the Baltic, are but branches. Truly inland seas, such as the Dead Sea and the Caspian, are in reality salt lakes which have no connection with the ocean. We cannot imagine a rise in the level of the

Mediterranean or the Baltic without a current immediately running out into the Atlantic; or a fall in those seas without a current immediately setting in, so as to equalise the level of the adjacent connected waters.

If, then, we find that on one part of a coast the rocks which were once below the sea are now above it, but that no such change has taken place in another part of the coast; still more, if we find that in some other part rocks that were once above it are now below it, we have the most convincing proof that it is the rock that has moved above or below its former level, and not the sea.

Movements of elevation and depression in the crust of the globe take place sometimes during earthquakes, sometimes without them, the motion in the latter case being quite gradual and imperceptible, except by its results. I proceed to select a few instances of each kind of motion, chiefly from Sir Charles Lyell's *Principles of Geology*.

Elevation and Depression during Earthquakes. *South America.*—One of the great earthquakes which so frequently shake the western coast of South America happened on the 20th of February 1835, and we have accounts of what took place then from three most trustworthy witnesses—Mr. Caldcleuch, Mr. Darwin, and Admiral (then Captain) Fitzroy. It was felt in all places between Chiloe on the south and Copiapo on the north, a distance of more than 1000 miles, and between the city of Mendoza on the east and the island of Juan Fernandez on the west, a distance of at

least 600 miles. It affected, then, an area of 600,000 square miles, a space equal to the British Islands and France and their adjacent seas. Admiral Fitzroy was at Talcahuano, the port of Concepcion, and he says that after the earthquake there was a belt of coast four or five feet in height, which, even at high water, showed beds of dead mussels and shell-fish like limpets, and withered sea-weed, all still adhering to the rocks. This raised beach gradually sank again until the part above high-water mark was not more than two feet high. The small island of Santa Maria, 25 miles south-west of Concepcion, was visited by Admiral Fitzroy in March and April, and he found the southern end of the island had risen 8 feet, the middle 9, and the northern extremity 10 feet, the island being seven miles long. On steep rocks, where vertical measures could be taken, beds of dead mussels adhering to the rocks were found 10 feet above high-water mark. Before the earthquake a rocky flat, just covered by the sea, with a few rocks only appearing, stretched round the northern part of the island. After the earthquake this was all dry, with acres of dead shell-fish, the stench of which was abominable.

The soundings all round the island had also been diminished in the same proportion, the whole sea having become shallower in consequence of the lifting up of its bed.

This elevation did not extend over the whole area shaken by the earthquake, as in some part of the coast no change was perceptible.

Mr. Darwin says that simultaneously with this earthquake a train of volcanoes in the Andes opposite Chiloe burst into eruption, and continued active for twelve months, and that the ground near them was not shaken at all, the disturbing force being apparently relieved by the eruption.

This is only one of many similar cases that have happened in this century in the same country. In the earthquake of 1822 it was supposed that 100,000 square miles were lifted up from 2 to 7 feet, and the rising was thought to be even greater in the interior of the country, in consequence of some watercourses running more rapidly, or down a steeper slope, than they did before. Mrs. Graham, who was one of the describers of the effects of this earthquake, after mentioning the raising of the beach near Valparaiso, says that she observed several other lines of older raised beach, one above and beyond another, parallel to the shore, the upper one being 50 feet above the sea.

Mr. Darwin, in his *Geological Observations on South America*, describes the beds of sea shells which he found at various heights above the sea, both on the east and west coasts of South America. Near Valparaiso he found them up to an altitude of 1300 feet, the shells at the lower levels being fresh, but those at greater heights being more and more brittle and decomposed, from having been so much longer exposed to the weather. They were imbedded in a reddish mould, which, when examined by the microscope, was found to be partly made up of minute fragments of sea

urchins and other marine animals, showing it to have been the old sea bottom. The mould, when crushed, emitted a smell like guano. He got evidence that besides sudden elevations during earthquakes, there had been a slow and imperceptible movement of elevation between the earthquakes; and it appeared most probable that the elevation had been greater inland than on the coast.

While he found shells up to 1300 feet near Valparaiso, he did not find them at greater heights than 350 feet southwards in Chiloe, or 250 or 300 feet northwards, towards Coquimbo, or at Callao near Lima. At the latter place, indeed, subsequent depression seemed to have occurred.

Judging by the cliffs and terraces formed by the erosion of the sea on both sides of the Continent, there must have been long pauses in the movement, during which the land remained stationary, and was eaten into by the sea waves.

Raised beds of sea shells were found starting from Eastern Tierra del Fuego for 1180 miles northwards along the eastern coast, and 2075 miles along the western. For a length of 775 miles they occur in the same latitudes on both sides.

Altogether it is probable that the shores of the Pacific have been lifted up recently, in a geological sense, from Lima southwards for 2480 nautical miles, a distance equal to that from the Red Sea to the North Cape of Scandinavia, part of the elevation having certainly taken place while the country has been in-

habited by man, and being even now in progress.—(*Geological Observations on South America*, by C. Darwin: London, 1846, chap. ii.)

Cutch.—On the south-east side of the delta of the Indus there is a district called Cutch, between Sinde and Goojerat. In June 1819 it was shaken by an earthquake which ruined the principal town, Bhooj, and was felt far into India. After the earthquake a tract of land, 2000 square miles in area, was overflowed by the sea, and made into a salt lagoon, while along the northern margin of this tract a belt of land, 50 miles long and 10 to 16 miles wide, that had been previously a dead flat, was raised into a ridge 10 feet high. The inhabitants called this the Ullah Bund, or "mound of God."

New Zealand.—A great earthquake happened in New Zealand in the year 1855, after which it was found that the tide did not run up the river Hutt, on the north side of Cook's Straits, so far as it did before by five miles, while on the south side of the Straits it ran five miles farther up the river Wairua than it did before, showing that the land had risen on the north and sunk on the south side of the Straits.

A letter quoted by Mr. Mallet gives the vertical elevation at four or five feet, the maximum being at the Rainatuka range, near Port Nicholson, and dying away to nothing at Wangarna on the west coast, and Castlepoint on the east.

Sir C. Lyell states, on the authority of Mr. E. Roberts, R.E., that a line of fracture (called a fault by geologists) was shown at the surface, running at least

90 miles from south to north—the older rocks on one side of this line being lifted to a maximum height of nine feet, while the more modern (tertiary) rocks on the other side of it remained unmoved.

Movements without Earthquakes.—In speaking of South America, it was mentioned that Mr. Darwin found good reason to believe that the elevation of the land took place not only by jumps and starts during great earthquakes, but also slowly and imperceptibly in the intervals between the earthquakes. It also appeared that intervals of movement had alternated with intervals of rest, and movements of elevation with movements of depression in some parts.

We have now to learn that in some parts of the world, where no great earthquakes have happened during the periods of history, there have, nevertheless, been slow and imperceptible movements of the land.

The two best instances of these are the elevation of Scandinavia and the depression of parts of Greenland.

Scandinavia.—The rise of Scandinavia was noticed by Celsius early in the last century, and subsequently by Linnæus, but erroneously attributed to the fall of the sea. Von Buch in 1807 was convinced that the whole country was rising, Sweden perhaps more than Norway, and the northern more than the southern parts.

As there are no tides within the Baltic, and the coast is made of hard rocks and fringed with numerous islets, it is peculiarly favourable for making exact observations on the relative level of the land and sea. South of Stockholm no rise is perceptible in the land,

and it appears that there has even been depression; for *at Malmö at the southern point of Sweden, a high* wind blows the sea water over one of the streets, and excavations have shown the surface of older streets at a depth of six or eight feet lower.

North of Stockholm, however, the elevation is obvious; the fishermen and pilots are all aware of it, although they attribute it to the fall of the sea. Constantly passing in their boats in the shallow water among the islets, they become minutely and accurately acquainted with the depths of the channels and the size and form of the rocks, and they find the channels become shallower or actually dry, the rocks higher out of the water and connected by reefs, the detached islets united into larger islands, rocks formerly covered showing their heads above water, and all the other necessary indications of the rise of the rocky bottom of the sea above its surface. The officers of the government pilot establishment have had marks cut in the hard rocks at a certain height above the sea-level, and these have been found afterwards to be higher above it than when they were cut. The movement is not exactly equable, and elevation appears in some cases to have alternated with depression, but it is believed that the land is rising at a rate of a few inches in a century a little north of Stockholm, and more rapidly the farther we go north, till it amounts to five or six feet in a century about the North Cape.

That it has been going on for many centuries is shown by the existence of great beds of sea shells many

miles in the interior of the country, and at heights of as much as 200 feet above the sea. M. Alex. Brongniart, on removing part of a bank of shells which rested on gneiss, at a height of 200 feet above the sea, near Udevalla, found barnacles still adhering to the rocks; and Sir C. Lyell in 1854, at Kured, 2 miles north of Udevalla, also found them at a height of 100 feet above the sea, and was able to break off pieces of the rock with the barnacles still adhering, and the rock still coated with marine polyzoa (*Cellepora*), with which the rocks now beneath the sea are often encrusted.

These beds of sea shells have been found 50 miles from the North Sea, and 200 feet above it, on the northern borders of Lake Weiner, and 70 miles from the Baltic, on the shores of Lake Maeler, so that much land must have been added to the country within a comparatively recent period.

The space over which indications of the rise of land have been traced is more than 1000 miles across.

Greenland.—Captain Graah of the Danish navy, and Dr. Pingel, surveyed the western coast of Greenland between the years 1823 and 1832, and arrived at the conclusion that the land had been sinking for the last four centuries between Igaliko, in 60° 43′ N. lat., and Disco in 69°, a space of 600 miles. "Ancient buildings on low rocky islands have been gradually submerged, and experience has taught the aboriginal Greenlander never to build his hut near the water's edge. In one case the Moravian settlers have been obliged more than once to move inland the poles upon which their

large boats were set, and the old poles still remain beneath the water as silent witnesses of the change."

Mediterranean.—Sir C. Lyell also shows that similar changes have taken place in the Mediterranean. The three upright pillars of the temple of Jupiter Serapis, near Puzzuoli, have been depressed to a depth of 19 feet below the sea, to which height they are bored full of holes made by a species of marine mollusc, and have since been lifted up again into dry land.

He states also, on the authority of Captain Spratt, R.N., that the island of Candia (anciently Crete), which is about 135 miles long, has been elevated at the western end about 25 feet, so that old ports or docks are left high and dry, while it has been depressed at the eastern end, so that the ruins of old Greek cities are to be seen beneath the water.

Difficulty of proving Depression.—When rock is lifted up above the sea it will be very likely to bring up with it the proofs of its having been formerly below water; but when that which was once dry land sinks below the sea, it shortly becomes altogether removed from our inspection, and, in the absence of historical records, we can have little or no evidence of its former existence.

Taking natural evidence only then, elevation will always appear to have been more general than depression in most parts of the Earth. Within some parts of the tropics, however, we have in coral reefs a very singular natural standard by which to measure the amount of depression, as will appear in Chapter VI.

General Conclusion.—Combining all the evidence, of which a few isolated examples have been here given, and taking into account that presently to be derived from the form of coral islands, we arrive at the conclusion that the crust of the Earth is in frequent if not in constant movement in some part or other; large parts remaining stationary for long periods, while others are being elevated, and others again depressed.

We know that the sea, with its present level, has once flowed over the spots now occupied by our loftiest mountains. On the other hand, there is nothing improbable in the belief that land once existed where now the deepest parts of ocean are to be found. Mr. Darwin observes of the earthquake which he felt near Valdivia in 1835: "It was something like the movement of a vessel in a little cross ripple, or still more like that felt by a person skating over thin ice which bends under the weight of his body. A bad earthquake at once destroys the oldest associations; the world, the very emblem of all that is solid, has moved beneath our feet like a crust over a fluid."

The Geologist, as he pursues his studies, learns to generalise this feeling, and to apply it to the whole crust of the Earth during all Geological time. He finds that it always has been, as it now is, utterly unstable, rising here and falling there, with long slow undulations, ever shifting under the liquid Ocean, and moving it from place to place, as parts of its old bed are lifted up above its surface, and new hollows formed by the sinking of other shores.

CHAPTER V.

MINERALS AND IGNEOUS ROCKS.

When we hear of such immense quantities of materials as those which compose volcanic mountains being ejected from beneath the crust of the earth on to its surface, as described in Chap. II., the question naturally occurs to us, What are these materials made of? I will proceed to answer this question in a general way, disregarding as far as possible mere technicalities; although the subject can never be thoroughly understood without a complete mastery over those technicalities.

Since the lavas and igneous rocks proceed from the interior of the Earth, the question as to their composition is very nearly the same as asking what materials the inside of the Earth itself is made of.

Chemical Nomenclature.—Chemists now tell us that there are between sixty and seventy simple or elementary substances, and that everything in or about the earth consists either of one of these, or of a compound of two or more of them. Except fifteen, these are all metals, as pure Iron, Copper, Tin, Lead, Zinc, Silver, Gold; of these metallic elements some few are common, the rest are never seen in their simple state except in the laboratory of the Chemist. Of the other fifteen, Phosphorus, Sulphur, and Carbon, are examples;

while others, such as Silicon, Boron, Iodine, are very rare in their simple state; and others, when in that condition, are mere gases, such as Nitrogen, Hydrogen, and Oxygen.

The last-named element, Oxygen, is always combined with one or more of the others in all the inorganic substances of which the crust of the earth is composed, as well as in the Water which rests on its surface. *Mixed* with Nitrogen it constitutes the Atmosphere, *combined* with Hydrogen it forms Water; in union with Silicon it makes the substance Silica; and when united with the metals Aluminium, Calcium, Magnesium, it converts them into Alumina, Lime, and Magnesia. These unions of two elementary substances are denoted in chemistry by the termination "ide;" Silica, Alumina, Lime, etc., being termed Oxides of Silicon, Aluminium, Calcium, etc. These "ides" have sometimes no special name in ordinary use, like Lime for the Oxide of Calcium, so that we speak merely of the Oxide of Manganese or the Oxide of Iron, unless we choose to call the latter "iron rust."

The oxides of the *metals* combine with the elements of water (Hydrogen and Oxygen) to form compounds called *Basic Hydrates;* the simple Oxides being called in this relation *Anhydrides, i.e.* without water, as Lime or Oxide of Calcium; while Potash is a Hydrate of Potassium. The term *Base* is applied indifferently to both Hydrates and Anhydrides of the metals.

The oxides of the *non-metallic* bodies, on the other hand, when they combine with the elements of water,

form compounds called *Acid Hydrates*, analogous in composition to Basic Hydrates, but opposite in their chemical properties, and capable of neutralising Bases. Sulphuric Acid and Carbonic Anhydride are examples of an Acid Hydrate and Anhydride respectively.*

Though most Acids are thus formed from Oxides and contain Oxygen, yet there is another class of Acids which Chlorine and some other non-metallic elements form, by simply combining with Hydrogen; these are distinguished by the prefix "hydro," as Hydrochloric Acid. When Acids and Bases mutually act upon each other, and an interchange takes place between the Hydrogen of the Acid and the metal of the Base, *Salts* are formed, and these are denoted by changing the termination "ic" of the Acid into "ate," as Carbonate, Sulphate, Silicate; thus, if Sulphuric Acid be poured upon Soda (Sodic Hydrate), Water and Sodic Sulphate are formed; in this case Sulphuric Acid is the Acid, Soda is the Base, and Sulphate of Sodium (or Sodic Sulphate) the Salt.

Such Salts consist of a metal combined with Oxygen and some other non-metallic element, but the Salts formed by such an Acid as the Hydrochloric only consist of a metal and a non-metal, "ides" in fact, *e.g.* Sodium Chloride or common salt.

All names, then, ending in "ide" denote a union of

* These were at one time both included under the term Acid, as Basic Hydrates and Anhydrides are included under the term Base, but Hydrogen being now considered an essential element in Acids, it is therefore only to the Hydrates, and to bodies like Hydrochloric Acid, that this term is applied.

two elements only, while all those ending in "ate" denote a union of at least three elementary substances.

In the instance given above, Acid and Basic Hydrates acted upon each other, but Salts may also be formed by the action of Basic Anhydrides on Acid Hydrates, and of Acid Anhydrides on Basic Hydrates,—it is in the last way that glass and other silicates are artificially produced. Thus, by mixing Silica (Silicic Anhydride) with Potash or Soda and other Basic Oxides, and heating them to a high temperature, they will unite and form a liquid which, on being cooled, makes the transparent substance glass.

Precautions have, however, to be taken in the manufacture of glass as to the rate and conditions of cooling, as well as regards the proportions of the ingredients, otherwise the glass will become opaque and form what is called a slag, or will even crystallise and form a stone. Slags from a glass-house and those from an iron-furnace are all silicates of the different basic substances, and are in reality artificial igneous rocks. Porcelain, china, and pottery, are composed of Silicate of Alumina, either indurated or half fused. The silicate of Alumina, as also the Silicates of Lime and Magnesia, are very infusible by themselves, but are readily dissolved in the melted mass of other more fusible silicates, as those of Potash, Soda, or Iron; here, the more fusible silicates are said to act as a flux to the more infusible ones; the infusible silicates, however, when simply mixed together, melt at a very much lower temperature than they would separately.

Silicates are the only salts which occur as constituents of the igneous rocks, and the three above mentioned occur very abundantly; Silicate of Alumina, united with some more fusible compound, forming the minerals called Felspar, while Silicate of Magnesia, combined with the Silicates of Lime or Iron, forms those known as Augite or Hornblende.

Crystallisation and Cleavage.—Before entering upon any description of minerals, a short explanation of the above terms is requisite. A crystal is a regular geometrical solid, whose internal structure is related to its external form; in consequence of their symmetrical mode of construction, crystalline bodies split with greater facility in certain directions than in others, this property is called Cleavage. The surface planes of crystals have certain definite relations to lines fixed in space, which are assumed to intersect in the centre of the crystal, and are called *Axes;* by means of these, crystals may be classified under six systems, as below:—

1. *Isometric or Cubic System:* three axes, all equal and at right angles; ex.—the cube, as in Fluor-spar; the octohedron with its sides equilateral triangles.

2. *Tetragonal or Pyramidal System:* three axes at right angles, the two laterals equal; ex.—the square prism; and the octohedron with its sides isosceles triangles, as in copper pyrites.

3. *Hexagonal or Rhombohedral System:* four axes, the three laterals equal and at angles of 60°; ex.—the six-sided prism, as in Quartz; the rhombohedron, as in Calc-spar.

4. *Rhombic or Prismatic System;* three unequal axes at right angles; ex.—the rhombic prism, as in Topaz.

5. *Monoclinic System;* three axes, two at right angles and one at right angles to *only* one of these; ex.—the oblique rhombic prism, as in Orthoclase Felspar.

6. *Triclinic or Anorthic System;* three axes, all unequal and oblique to each other; ex.—the doubly oblique prism, as in Oligoclase Felspar.

We may now proceed to describe those minerals which are the essential constituents of Igneous rocks.

1. The first to be mentioned is pure Silica itself, forming the mineral *Quartz* or Rock Crystal, sometimes called Irish Diamond, Bristol Diamond, Kerry Diamond, etc. It occurs either in crystals belonging to the third or Hexagonal system, or as a compact, hard stone, generally milk-white. Amethyst, Cairngorm, Agate, Jasper, Carnelian, Onyx, Catseye, Lydian Stone, Bloodstone, Opal, Chalcedony, Chert, Flint, are all mere varieties of Quartz, stained of various hues by slight admixtures of Iron, Manganese, or other colouring matter. When Quartz occurs in an igneous rock it is usually a greyish, semi-transparent, glassy-looking, irregularly crystalline particle, which cannot be cut or scratched by even the best steel knife.

2. *Felspar* is a name for a family of minerals rather than for one. They all consist of Silicates of Alumina, combined with Silicates of Potash, Soda, or Lime.

The most important felspars are given in the following Table, together with their composition and system of crystallisation.

NAME.	COMPOSITION.	SYSTEM.
1. Orthoclase .	Potash Felspar	Monoclinic or Orthoclastic.
2. Hyalophane .	Baryta-potash ,,	
3. Albite . .	Soda ,,	Triclinic or Plagioclastic.
4. Oligoclase .	Soda-lime ,,	
5. Anorthite .	Lime ,,	
6. Labradorite .	Lime-soda ,,	

Orthoclase or Common Felspar is a highly silicated and therefore very infusible mineral. Hyalophane is very rare, but remarkable as being the only other monoclinic felspar. Albite, of rarer occurrence, is as highly silicated as Orthoclase, but contains Silicate of Soda instead of Potash, and has a different crystalline form; Oligoclase contains less Silica in combination with the other substances, which are Soda and Lime.* Labradorite and Anorthite are the lowest silicated Felspars, having a higher proportion of Silicates of Alumina and Lime, and being therefore very fusible species.

The Felspars, as seen in igneous rocks, generally form long and rather narrow opaque crystals, with a bright surface shining like satin. They are usually light coloured, either white or some shade of red or green. It requires a heavy pressure to scratch the surface of one of these crystals with a good knife, a test by which they may be readily distinguished from Calcspar, which is easily scratched.

The triclinic Felspars may be distinguished from the monoclinic,—*e.g.* Oligoclase or Labradorite from

* It has lately been supposed that Oligoclase is not a distinct species, but a compound of Anorthite and Albite in alternate layers.

Orthoclase,—by the presence of fine parallel striæ along the surface of certain of the cleavage planes.

3. *Hornblende and Augite.**—Under these names a group of minerals is included which do not differ so much from each other in composition as do the different Felspars, since they are all almost equally basic, or, in other words, have a nearly equally large proportion of metallic substances combined with the Silica.

Magnesia plays the same prominent part in them as Alumina does in the Felspars; their essential composition being a mixture of Silicate of Magnesia with Silicate of Lime; the latter substance being often more or less replaced by Iron or Manganese. Diallage and Bronzite are varieties of Augite; Tremolite, Actinolite, and Asbestos, are varieties of Hornblende; Hypersthene is an allied mineral, being a Silicate of Magnesia and Iron, but crystallising in the rhombic system, while Augite and Hornblende belong to the monoclinic system. Hornblende and Augite are usually seen in rocks as dark green, sometimes black, crystals or crystalline particles, some of the varieties being of a paler green.

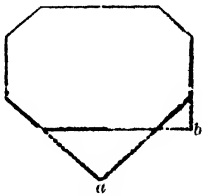


Fig. 4.

Hornblende crystals have generally a fibrous structure and a silky lustre, by which they may often be distinguished from crystals of Augite. If the crystals are large, in a transverse section of Augite lines con-

* These have been thought, with some reason, to be the same mineral crystallised under different circumstances.

tinued along the alternate faces make nearly right angles, as at *a* and *b*, Fig. 4, while in Hornblende no two alternate sides produced make right angles.

4. *Mica.*—This is also a name for a family of minerals varying a good deal in composition, and belonging to several crystalline series, but all alike in having a bright metallic lustre, and splitting readily into very thin flexible horny-looking plates, which are generally more or less transparent. They are composed of a mixture of Silicate of Alumina with Silicates of Potash, Magnesia, etc., the proportion of the basic materials being greater than in any of the Felspars, and some of them, as the Black Mica or Lepidomelane, more basic than Augite or Hornblende, but not containing any notable quantity of Lime.

This Black Mica is an abundant mineral in some Granites, while in others the White Mica or Margarodite or Pearl Mica is still more abundant. This generally has a greenish tinge. Muscovite or common Mica* is more usually yellowish brown, and is so transparent, and occurs in such large plates in Siberia and other parts of the world, as to be used instead of window-glass. The Micas have various degrees of fusibility, but are all easily scratched with a knife.

Having thus given a rough general account of the minerals that form igneous rocks, it will be now possible to give a similarly general description of the rocks themselves.

* This is sometimes called Talc in commerce, but the true mineral Talc is a very different substance.

It is found that igneous rocks differ in the following particulars :—

1. In having different mineral components.
2. In having different textures.
3. In having different structures.

Among the essential constituents the minerals of the Felspar group are by far the most important and constant, forming in fact the basal substance of all truly igneous rocks ; the particular kind of Felspar, however, differs in different rocks, and these variations afford one method of classification.

Again, there is considerable variation in texture, but with the exception of the completely glassy states, such as Obsidian, they are all more or less crystalline ; some, like certain Felstones and Basalts, are quite compact, or show no sensible crystalline particles, others, like Granite, exhibit crystalline granules of many various sizes ; and sometimes one mineral exists in large well-formed crystals, while the other components form a comparatively compact base or matrix,—the rock is then said to become *porphyritic*.

In all cases the matrix itself discloses under the microscope one of three conditions ; it is either wholly crystalline, or semi-crystalline, or glassy.

With regard to structure, igneous rocks may be massive, jointed, or columnar, differences which will be noticed in a future chapter. Certain smaller structural characters, however, need a passing word of explanation; —the surface of a lava stream is generally *scoriaceous*,

i.e. rough and cindery; internally the mass is frequently *vesicular* from the disengagement of gaseous matters; and when these vesicles have been subsequently filled up with some mineral so as to look like almonds stuck in a pudding, the rock is called *amygdaloidal*, from the Greek word *amygdalon*, an almond.

In the following Table igneous rocks are classified primarily according to their mineralogical composition, and secondarily according to their intimate structure.*

	Matrix wholly Crystalline.	Matrix semi-Crystalline.	Matrix Glassy.
I. Orthoclase Felspar.			
a. Quartziferous .	Granite . .	Quartz-felsite	Quartz-trachyte.
b. Quartzless . .	Syenite . .	Orthoclase-felsite, Minette	Sanidin-trachyte, Pitchstone, and Obsidian.
II. Plagioclase Felspar.			
a. Oligoclase, sometimes with quartz	Diorite . .	Porphyrite .	Andesite.
b. Labradorite, or an allied mineral; no quartz	Gabbro, Diabase, Dolerite, Basalt	Some Basalts?	Tachylite.

* It is now generally admitted that the old classification into Lavas, Traps, and Granites, though somewhat commendable from its very vagueness, was certainly conducive to much confusion and misconception. The above Table forms the basis of the classification which Mr. Bonney has adopted for his forthcoming *Student's Handbook of Lithology*, and I have to thank him for the privilege of using it.

Granite consists of Felspar, Mica, and Quartz, the Felspar being in greatest quantity, and always one of the most siliceous varieties of the mineral, namely Orthoclase, or more rarely Albite, with the addition of Oligoclase in some Granites. The Mica is either the white, green, brown, or black variety, or a mixture of two or more of them.

Granite is always crystalline, but the crystals are sometimes minute, sometimes large, and it becomes porphyritic by the development of Felspar crystals much larger and finer than the rest. There are red, white, and grey varieties of Granite, according to the colours and relative abundance of the different minerals.

A block of coarsely crystalline Granite is a very good one to teach the appearance of the commoner varieties of the minerals. The Mica may be at once distinguished by its metallic lustre, and by its being so easily split into flakes by the point of a penknife. The Felspar crystals may be known by their being quite opaque but glistening, and by their flat oblong faces. The Quartz is more glassy-looking and semi-transparent, which often gives it a grey look; it occurs commonly as irregularly-shaped particles or rough granules in the interstices of the other minerals.

All the crystals, however, are so interlaced and entangled with each other that it often requires close examination to perceive them, and no one crystal is perfectly formed, the growth of each being hindered by that of its neighbours.

Syenite.—As now defined, this rock consists of Orthoclase and Hornblende (sometimes with Oligoclase and Mica). It is distinguished from Diorite, described below, by the presence of Orthoclase, and from Granite by the absence of Quartz.

Between Granite and Syenite there is an intermediate form called *Syenitic* or *Hornblendic Granite* ; it may be considered as Granite in which the Mica has been replaced partially or entirely by Hornblende, so that it consists of Quartz, Orthoclase, and Hornblende, with little or no Mica.

Granitic rocks have never formed lava streams, but have always cooled and consolidated at some considerable depth, and all Granite now at the surface has been uncovered by the process of *denudation*, as will be explained hereafter; Granites often send veins and dykes into the rocks with which they come in contact, and form therefore *ir*ruptive or intrusive masses, but are never *e*ruptive rocks, which can only proceed from volcanic vents.

Felsite is composed essentially of Orthoclase Felspar, with a variable mixture of free Quartz. It is usually smooth and compact, and of a pale colour, either green, grey, or reddish, and usually weathers whitish outside. If a thin slice of the rock be examined under the microscope, the matrix is seen to present an imperfectly crystalline character, possessing the property of double refraction, though definite crystalline grains cannot be distinguished ; this has been called the "*felsitic structure.*" When the rock exhibits porphyritic crystals of Quartz, it

is called a *Quartz-felsite;* when there is no free quartz it may be called *Orthoclase-felsite;* and when Mica occurs in considerable quantity as an additional ingredient it is termed *Minette.*

Felsite is found both in dykes and sheets; it sometimes becomes nodular or concretionary, and occasionally assumes the columnar structure.

Trachyte is composed essentially of Felspar alone, and generally of Sanidine, a variety of Orthoclase. In this and all other rocks under the third column the matrix is a homogeneous glass, without any trace of double refraction.

Trachyte is sometimes dark-grey or black, but more often light-coloured, greyish, greenish, or even white; it has usually a rough almost prickly feel, even when compact; it is sometimes vesicular or scoriaceous, but often compact or crystalline and sometimes porphyritic. Just as in Felsite, we have a quartziferous and a quartzless variety, the former being called *Quartz-trachyte* (also *Rhyolite* or *Liparite*), the latter *Sanidine-trachyte.*

Pitchstone and *Obsidian* are probably most nearly related to Quartz-trachyte in chemical composition; some, however, may belong to ordinary Trachyte or to Andesite; Pumice is simply the frothy scum of scoriaceous trachytes.

Diorite consists of Oligoclase and Hornblende; it is sometimes very compact, minutely crystalline, and greenish-black in colour, but more often it is granular or coarsely crystalline, so that the rock has a mottled

black and green or black and white appearance; scattered crystals of Quartz occasionally occur. Like Granite and Syenite it is an intrusive rock, never an eruptive one, and therefore only occurs in dykes and thick masses that have once been buried far underground.

Porphyrite has the same felsitic matrix that is found in Felsite, but the Felspar is Oligoclase, usually with crystals of the same mineral scattered through the base; Quartz is a rare adjunct, but Hornblende and Mica are not uncommon.

Andesite is a Trachyte rock of a brown green or grey colour, with a coarse conchoidal fracture; its essential constituent is Oligoclase, with either Hornblende or Augite, Mica, and sometimes Quartz.

Gabbro or Diallage-rock is a granular compound of Labradórite and Diallage, usually coarse-grained and varying much in colour according to the varieties of the two minerals. *Hyperite* or *Hypersthenite*, being composed of a similar mixture of Labradorite and Hypersthene, may be looked upon as a variety of Gabbro. Both are originally deep-seated rocks, occurring mainly as intrusive bosses among other rocks.

Dolerite and Basalt are composed of a Lime-felspar, generally Labradorite, and an Augitic mineral, in equal or nearly equal mixture. In texture they vary from coarse crystalline Dolerites to compact Basalts which look and feel quite smooth when broken open; they are sometimes porphyritic with Augite, and also occur in the vesicular or amygdaloidal condition; they fre-

quently become columnar in structure, making ranges of hexagonal or many-sided pillars. They often contain Iron, are commonly black in colour, weathering brown, and are always heavier than the Trachytes.

Diabase and *Melaphyre* are probably only varieties of this group; in some Dolerites Nepheline or Leucite replaces the Felspar, producing rocks which have been called *Leucilite* and *Nephelinite* respectively. *Tachylite* has the same composition as Dolerite, but is of a glassy texture.

Of the rocks above described, Granite, Syenite, and Diorite would under the old terminology be grouped as Granitic or Plutonic rocks; the rest of the first column and those of the second would be called Traps, though by some Dolerite and Basalt were placed with those of the third column under the head of Lavas or Volcanic rocks.

The Felsite and Porphyrite groups were united under the name of *Felstones*, a term which is still kept as handy and useful for describing rock-masses in the field, and labelling specimens therefrom before they can be submitted to the searching test of the microscope. In the same way the term *Greenstone* may be retained, under which Diorite, Hyperite, Gabbro, and Diabase used to be included, together with some of the older and coarser Doleritic rocks. The term *Greystone* may also very well be used in a similar way to include certain not very characteristic Felsites and Trachytes, with others in which the minerals Nepheline and Leucite more or less replace the Felspar, all being of a grey colour and having a tolerably compact texture.

Volcanic Ash and Agglomerate.—These consist of the fragments ejected from a volcano during the progress of an eruption, and are therefore only associated with the eruptive rocks, the more deep-seated or Plutonic rocks never having anything of the nature of Ash connected with them. The fragments vary from large blocks down to the finest and most impalpable powder; in the latter case the resulting rock is called an *Ash* or *Tuff*, in the former an *Agglomerate*,—this is usually a confused and tumultuous accumulation of materials in which igneous and sedimentary rocks are often mixed up together and embedded in a powdery matrix. When indurated these masses have been called *Trappean Ash* and *Agglomerate*, and when still more altered, as in North Wales and the Lake District, they are often difficult to distinguish from truly igneous rocks, since they become compact in texture and show a porphyritic structure; such alteration comes under the head of *Metamorphism*, and will be explained in a future chapter.

Origin of Igneous Rocks.—Since Granite always consists of highly silicated minerals together with a superabundance of uncombined Silica which appears in the form of Quartz, it is not unreasonable to look upon it as the parent mass from which all the other varieties of igneous rock have been derived by the addition of more basic materials. We may be allowed to take it for granted that at a depth of a certain number of miles beneath the surface a temperature would be met with sufficient to fuse the most siliceous Granite. If a mass

of this were impelled by some force towards the surface, it may be supposed to meet with more or less of Alumina, Potash, Soda, Lime, or Iron, which should act as a flux to the Silica and prevent its solidifying, until it worked its way up to a certain position in the higher parts of the crust, or even until it was ejected out on to the surface. Those parts which happened to come in contact with a small proportion of these substances would form the Felsites, Trachytes, and Acidic Lavas, those parts which acquired a larger proportion of basic matter would form the Greenstones and Doleritic or Basic Lavas. The numerous intermediate varieties of rocks and Lavas, and the local peculiarities observable in them in some places, would be the result of the varying proportion of the materials which the igneous mass happened to meet with and absorb, and of the greater or less pressure under which it was cooled.

Note.—This view of the relations of igneous rocks to one another derives strong support from the recent investigations of Mr. Judd (*Q. J. G. S.* xxx. p. 292) who has shown that the Granitic masses of the Inner Hebrides have had a close connection with the ancient Lava streams of the neighbourhood, and that Ben Nevis itself is only the core of an old volcano, its basal Granite being found to pass into the Felsites and Felstone Lavas which form the peak above.

CHAPTER VI.

ROCKS FORMED OF ANIMALS AND PLANTS.

Carbon and Carbonic Acid.—In addition to the substances described in Chapter V., we must now say a word or two more on the substance called Carbon, which was there passed over slightly.

The crystal of pure Carbon is the Diamond, which according to Sir D. Brewster may be only a crystallised gum. When in an earthy state pure Carbon forms Graphite or Plumbago.

Carbon is the principal constituent of wood or vegetable matter, the rest of that substance consisting chiefly of Oxygen and Hydrogen with a little Nitrogen, the Oxygen and Hydrogen being chiefly combined in the form of Water.

Peat, Lignite, and Coal, are made of the same materials as Wood, each containing a larger proportion of carbon, in the order in which they are named, in consequence of the gradual abstraction of the other substances in liquid and gaseous forms during the decomposition of the vegetable matter.

Carbon also enters into the composition of animal matter, but animals are more varied in their composi-

tion than vegetables, and their carbon is principally combined with other substances.

Carbon, when combined with two proportions of Oxygen, forms Carbonic Anhydride, commonly called Carbonic Acid,* a substance universally diffused in small quantities through the atmosphere, and through all rain, spring, river, and sea water. Animals, when respiring, cause some of the inhaled Oxygen to combine with some of their Carbon and give out Carbonic Anhydride. Vegetables secrete the Carbon from the Carbonic Anhydride, and give out the Oxygen that was combined with it; they thus mutually serve each other, and keep up the balance in the atmosphere in which they live.

Carbonate of Lime.—Carbonic Acid combines with the earth Lime to make Carbonate of Lime, which is the principal substance comprising the hard parts of most animal bodies. In bone, indeed, and in the hard cases or crusts of crabs, shrimps, and lobsters, there is a large proportion of Phosphate of Lime: but all shells, the cases of sea-urchins, the bodies called corals or madrepores, and all similar animal structures, are composed of almost pure Carbonate of Lime.

But this is the identical substance of which Chalk, Statuary Marble, Oolite and all Limestones, whether hard or soft, are also composed, and most Limestones

* A true hydrate appears to be formed when this gas is dissolved in water, though it has not yet been obtained separately; it is this aqueous solution, however, that acts upon Chalk and other rocks, as mentioned below.

are obviously full of the remains of shells and fragments of animals such as those spoken of above. Many limestones, indeed, can be seen by the naked eye to be completely made up of such fragments, and these facts alone might induce us to look to the Animal Kingdom as the source from which all limestones must be derived. When a calcareous or limestone rock is exposed to the action of water containing Carbonic Acid, it is found to be dissolved by it. This is the explanation of the fact that caverns are more abundant in limestone countries than elsewhere, the water running along cracks underground widens them by dissolving the rock, and thus forms long passages and caves. All springs and rivers, then, which pass through any calcareous rocks contain Carbonate of Lime in solution. The most clear and sparkling waters often contain a quantity of dissolved limestone, just as the sea contains a quantity of dissolved salts and other matters, and both may be made by evaporation to deposit their contents in a solid form. Water trickling through the roofs of limestone caverns and partially evaporated as it falls, deposits the previously dissolved limestone it contained, in the form of Stalactites and Stalagmites ; and brooks and rivers, when broken into spray, in like manner deposit masses of limestone called Travertine or Tiburstone. Encrustations are made in this way both naturally and artificially, and the substance deposited is precisely the same as that of statuary marble, and is often just as crystalline, and will take as high a polish.

Much of this dissolved limestone, however, is of

course carried down into lakes and seas, and is there used up by the aquatic animals who secrete it from the water, and, by the hidden and mysterious chemical processes of their vital action, re-solidify it in the hard parts of their own bodies, just as we make the bones of our own skeletons out of the substances we eat and drink.

Thus we have followed the substance Carbonate of Lime through the various conditions in which it exists, first finding it in the hard parts of animals, then as a constituent of rocks formed from those animals, next in solution in water, by which it is carried down into seas and lakes, and there again taken up to form part of organic structures. To this continual circulation of Carbonate of Lime must be referred many of those chemical changes to which the constituents of rocks are subjected. We will now consider how limestones come to be made up of the shells and fragments of organic beings.

Marine Animals secreting Carbonate of Lime.—The lower and minuter kinds of animals make up for their smallness and apparent insignificance by their immense abundance, and this is true especially of those animals that live in the water, and most especially of marine animals. Few persons form any adequate conception of the variety and numbers of animals that live in the sea, though Spenser, with a Poet's sagacity supplying the place of a Naturalist's knowledge, had long ago a true notion of it.

"O! what an endlesse worke have I in hand,
To count the seas abundant progeny,
Whose fruitful seede farre passeth those on land,

And also those which wonne in th' azure sky ;
For much more eath to tell the starres on hy,
Albe they endless seeme in estimation,
Than to recount the seas posterity ;
So fertile be the flouds in generation—
So huge their numbers, and so numberlesse their nation."
Faery Queene, Book iv., canto xii.

The lower orders of life, especially, such as the small Rhizopods (*root-feet*) and larger Actinozoa (*ray-animals*), produce results which would at first be thought impossible.

Among the Rhizopods are the animals known as Foraminifera (*hole-bearing*) which secrete Carbonate of Lime, while others, called Radiolaria (*ray-like beings*), secrete Silica or flint. The minute shells which these animals produce are of the most varied and beautiful forms ; they are mostly perforated by numerous holes through which the delicate tentacular processes of the animal are protruded. They exist in countless myriads in some parts of the ocean, and, as we shall presently see, have largely contributed to the formation of very thick beds of rock.

The Actinozoa include some of the animals formerly called Polyps. The Actinia or Sea Anemone may be taken as a type of them, so far as the kind of animal is concerned ; but those to which our attention is now called secrete Carbonate of Lime in the interstices of their fleshy or gelatinous parts, and form those stony masses which are known as Madrepores or stony Corals. The animals which form the Red Coral and the Sea-Fans, and other similar productions, form a separate

class of the same sub-kingdom.—(*See* Professor Reay Greene's *Manuals of the Cœlenterata and Protozoa.*)

This sub-kingdom is now known as the Cœlenterata (*hollow insides*), the animals belonging to it being mere little digestive sacs or stomachs, with a few external tentacles to enable them to keep their insides supplied with food. Those that form true Corals are united together into a common body by a kind of gelatinous mass, in which the individual cells are imbedded. This common mass also secretes Carbonate of Lime forming the framework of the coral, while the individual cells secrete the plates of the radiated orifices with which the corals are studded.

The compound bodies of the coral-forming Actinozoa are analogous to those of trees or shrubs. The stem and branches of a plant make a common body, from which the buds, which are the individual plants, spring in the first instance, but ultimately combine with it and extend it. In the same way corals consist of individual polypes united in a common body or trunk with or without branches and stems. Each genus and species of Coral has a peculiar character in its trunk or body by which it may be recognised, as well as by the form of its polype cells, just as a tree may be recognised by its leafless stem and branches as well as by its leaves or flowers.

Some genera of Corals, as the Mæandrina or Brainstone, form great masses or stools, which in some species become 8 or 10 feet in diameter; others, like Porites, make huge, shapeless banks of stone, 20 or 30 feet

across, or even larger; while others again form cups or undulating plates, or shrub-like clusters of branches, ending in pointed twigs or in rounded knobs. These masses, of whatever form and size they may be, have only their external film in the living state, each successive layer as it dies being covered with a new living growth, the continuation of the cellular structure below. The living parts often glow with brilliant colours, pink and purple, yellow and brown, and in one species a rich blue, but the dead portions are of the dull white we see in our museums.

Coral Reefs.—There are some kinds of these stony corals which live in our own and other extra-tropical seas, and are found at a depth of one or two hundred fathoms. The great reef-making corals, however, cannot exist in water that ever falls below 66° F., and are therefore confined to within a slight depth of the surface of intra-tropical seas, and even to those parts of them which are never invaded by currents of water colder than 66° F.—(Dana's *Coral Reefs and Islands.*) For this reason among others there are no coral reefs on the west coast of South America.

The limits of depth at which these reef-making corals live are variously stated at from 30 feet to 30 fathoms. According to my own experience I should be most inclined to assign the lesser depth, but every one now agrees that living reef-making corals do not exist beyond the greater one.

Coral reefs, however, are not composed of corals only. Shells of all kinds abound in and about them,

from the smallest and most delicate up to the huge Tridacna (or gigantic clam, as it used to be called), a bivalve shell, of which each valve is sometimes 5 feet long, 3 or 4 wide, and at least a foot thick. Crustacea and Echinodermata also live about coral reefs in countless myriads, but their bulk would be probably surpassed by the Reticularia or Foraminifera. In dredging inside the Barrier Reef of the north-east of Australia in depths of 15 or 20 fathoms, I often used to bring up bagful after bagful of a kind called Orbitolites, flat circular calcareous bodies about the size of a fourpenny piece, or from that to a shilling, and the sand on the shores of the mainlands and islands often consisted of nothing else but these bodies.

All these and many other kinds of animals separate the Salts of Lime, particle by particle, from the ocean, and contribute after death the solid parts of their bodies to the bulk of the reef.

The large solid corals, such as the Porites, the Mæandrina and Astræa, grow chiefly along the outer margin of the reef, where the surge of the ocean roars over them in continual breakers.

The more delicate branching Madrepores, and cup-like Explanaria and other forms, live either in the protected cavities of the outer margin, or in the lagoons or channels within the reefs.

As in each individual coral the living part is only the external film, so in the coral reef the living corals are only found in these superficial parts, chiefly on the mere margin of the reef. A coral reef is, in this re-

spect, something like a great peat bog, which is formed of living moss only just at the surface, the mass beneath being composed of the old dead layers.

On the upper surfaces of some coral reefs small sandy islands are formed, the coral sand being drifted by the winds and waves till it forms a bank reaching above high-water mark. But the mass of a coral reef is a solid rock, a coarse grey limestone, sometimes granular, but sometimes quite compact or even partially crystalline. This coral rock is often as hard as any of the limestones of our continents, and, except that it is occasionally porous or cavernous, makes as good a building stone.

It consists in some places of corals in the position of growth, but these are all imbedded in coral grains, and appear to be melting, as it were, into the surrounding parts, so that their original form can hardly be discerned. Some masses of coral rock present very good examples of the Oolitic texture, being entirely composed of small rounded grains, derived from the waste of corals and shells, which are enveloped in one or two concentric coats, like the coats of an onion. This structure is probably due to the action of rain-water dissolving some of the carbonate of lime from the coral sand above, and depositing it again while percolating through the beds below. Dr. Dana describes great beds of coral rock in some raised reefs as quite destitute of any fossil shells or corals in a recognisable form, a statement which I can fully corroborate from my own observation. Large masses of limestone, then, may owe

their origin entirely to the action of animal life, and be altogether composed of materials derived from the hard parts of animals, and yet show no more apparent trace of their origin than if they were beds of sandstone. Other beds, however, are full of shells or fragments of corals.

A coral reef, then, is mainly composed of triturated pieces derived from the destruction of its living margins, where the places of the corals destroyed are continually taken by fresh growths.

If the slope of the rocks below water be steep, the corals cannot grow far out from the dry land; but if the slope be gentle, they make a wider fringe of coral reef round the coast, the outer limit of the reef obviously being decided by the depth of the water. A reference to Fig. 5 will make this evident at once. Let the line S S represent the surface of the sea, and the line F F any depth below it at which corals cease to grow, and let A B and C D represent the surface of two lands of solid rock, A B having a steeper slope than C D.

Then suppose the submarine slope of those lands to be covered with a growth of coral from the beach at R down to G in each case, or to as great a depth as they can live, and suppose them, by the continued death of one layer and the growth of a layer above, to accumulate the reef R E G, it is obvious that the reef will be much wider off the gently sloping land C D than it is off the steep one A B, the distance of the outer edge of the reef E from the shore at R altogether depending on the slope of the original rock below water.

The outer edge of the reef, then, as it runs along the shore, would be like a line of soundings in a chart, and mark the position where a certain depth occurs immediately outside it. This relation between the width of the surface of the reef and the depth of water outside it, when once established, leads to very important consequences.

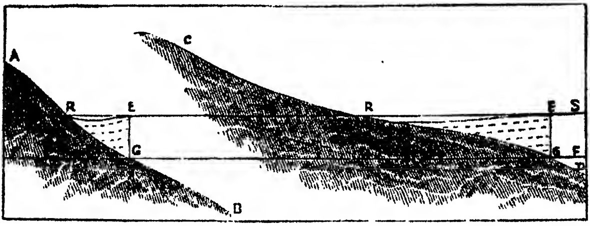


Fig. 5.

Suppose the land in Fig. 5, either A B or C D, were to subside vertically, so that after the reef had been completed up to the surface it was let down a few feet under water, and then left stationary for some years, the corals on the surface of the reef would grow and flourish, and again complete the reef up to the surface of low water. Or if the subsidence were to be continual, but so slow as not to surpass in amount the upward growth of the coral, it is obvious that the depth of water over the living surface of the reef would never be materially greater, whatever might be the depth ultimately attained by the rocky base on which they first commenced to grow. The height G E of the reef at its outer edge might be indefinitely

increased, and the width E R, to which the inner parts of the reef were extended over the sinking land, would be correspondingly increased according to the angle of its slope, but the great masses of coral would still continue to flourish about its outer margin, and at various parts inside where circumstances were favourable to them. If the subsidence were very slow and gradual, the annual waste of the hard parts of the corals and other animals swept by storms and currents over the inner surface of the reef would fill up its interstices and make it firm and solid rock, such as we find the great coral reefs to be.

This principle of the gradual sinking of the land and the upward growth and increase of the corals, especially on the outer margin of the reef, enables us to explain the origin of these greater coral reefs, which are much more remarkable than the mere fringes of coral which run along many tropical shores.

Barrier Reefs and Atolls.—The Fringing Reefs just described might be expected to form on all tropical coasts where no cold currents reached them, and no muddy rivers emptied themselves.

There are, however, many islands in tropical seas in front of which coral reefs are found at a distance of many miles from the beach of the dry land, their outer edge being nearly dry at low tide, but plunging steeply down into fathomless water, while a broad navigable channel or lagoon, of much less depth, and often encumbered with inner reefs, extends between this outer edge and the shore. These are called Barrier reefs.

Other coral reefs are found without any high land, or any rock whatever, except coral rock, visible about them, the only dry land being mere banks of coral sand, the debris of the reef itself heaped by the waves upon it. These have generally the form of great rings or loops of reef surrounding a lagoon of water; the depth of the ocean outside being very great, often unfathomable, while that of the lagoon inside varies from five to fifty fathoms. These are called Atolls.

Some Atolls have an unbroken outer margin, so that there is no entrance into the lagoon, others have many breaks or entrances in the outer reefs, so that the lagoon becomes a harbour. Barrier reefs in like manner have sometimes an outer margin unbroken for many miles, while sometimes the individual reefs on the outer edge are broken by numerous passages with water of 20 or 30 fathoms depth leading into the navigable channels between the outer reefs and the land.

Atolls are of all sizes, and almost of all shapes, varying from half-a-mile to 50 or 60 miles across; sometimes nearly circular, sometimes long and narrow, or curved, or indented in various ways. Barrier reefs conform generally in outline to the shore of the land of which they are the barrier, but they always come closer in shore where the land is high and steep, while where it is low and gently sloping they recede from the shore. Here we again perceive the analogy between the line of reefs and a line of soundings of any given depth.

Mr. Darwin, during his voyage as Naturalist to H.M.S. Beagle, between the years 1835 and 1840, was the first to explain the way in which Barrier and Atoll reefs had been formed from ordinary Fringing reefs, on the principle of depression of the land to which we have just alluded.

The outer edge of a Barrier reef marks the position, very nearly, of the outer edge of the original Fringing reef that grew along the shore when the land was at a higher level, or much more *out of the water*. As the sloping land slowly subsided, the sea would necessarily flow farther and farther over it, and the shore would therefore recede farther and farther from its old line. The corals, however, grew vertically upwards, or nearly so, so that the outer edge of the Barrier is not far from being directly over the Fringing reef that ran along the old line of the shore. The outer edge of the reef grows nearly vertically, because it is there where the most solid and massive corals flourish best, those best adapted by their form to resist the force of the breakers. Even these, however, are torn from their places, and rolled up on to the reef during occasional storms, but then they are often covered and protected there by a smooth stony coating of vegetable origin called Nullipora, which is sometimes 2 or 3 feet thick. The inner lagoon is partly filled by a more delicate growth of coral, and partly by the debris derived from the continued destruction of all the dead parts of the reef by the breakers and currents of the water.

If the Barrier reef entirely surround an island, and

the depression of the sea bottom be continued till the summit of the old island sink beneath the sea, while the corals still continue growing up to the surface, the Barrier becomes converted into a mere ring of coral, or Atoll, surrounding the lagoon or space of water which now extends completely over the sunken land.

This internal lagoon is itself often encumbered by inner reefs of coral growing on banks formed of coral sand and debris, or perhaps springing from some of the last disappearing pinnacles or crags of rock.

In Fig. 6 a rude attempt is made to illustrate this change by drawing successive lines, S S, S S, to represent the surface of the sea at different periods, as if the sea had risen instead of the island and sea bottom having been depressed. Let the shaded part be taken as the section of an island, and let the lowest line, S S,

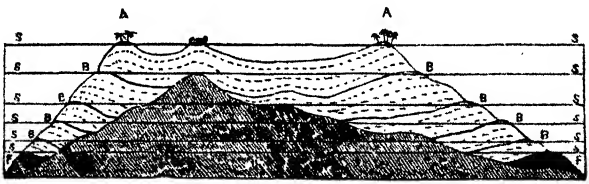


Fig. 6.
Conversion of a Fringing reef into a Barrier, and that into an Atoll.

represent the surface of the sea at one time, and let the two dark patches F F, represent the section of a Fringing coral reef which grew in the shallow water all round the island.

Then suppose the island to sink slowly and gradu-

ally, so that the sea flows more and more over it from time to time, as indicated by the successively higher lines S S, the corals still growing and accumulating upwards. The reefs will at once begin to form a Barrier round the sinking island, which will be maintained through all the spaces marked B B; and although the total distance from side to side of the reefs gradually diminishes, yet as the rocky land contracts at a greater rate, the width of the reef is comparatively larger until we reach the highest B B, when the last little point of land disappears. After that the Barrier becomes an Atoll, A A, or ring of reef without a central island, unless perhaps it be a bank upon an inner reef. Small islets form, however, on the reef itself, in consequence of banks of sand being thrown up by the waves. These become gradually covered by vegetation, and eventually by groves of cocoanut or other trees, and many of these little keys in the great ocean ultimately become the home of Man.

Since the publication of Mr. Darwin's book on Coral reefs in 1842, no one has doubted that this is a true history of the formation of Barrier reefs and Atolls. The Barrier is proof of the former greater extension of a land that has partially sunk. The Atoll is the tomb and monument of an island altogether buried beneath the waves.

Soundings have been made close on the outside of Barriers and Atolls, in several cases, showing that they spring from depths of at least 180 or 200 fathoms, the slope of the reef being sometimes rather gradual for a

little way, and then steep, sometimes seeming to plunge directly into deep water.

Close outside the greater part of the Barrier Reef of Australia, no bottom was ever touched by the surveying officers of H.M.S. Fly, with lines of 100 or 120 fathoms, and in one place, in a bight in the reefs, and within their general outline, a line 1800 feet in length was let go without reaching the bottom.

We may, therefore, pretty confidently assume that the outer edges of many Barriers and Atolls rise from a depth of at least 2000 feet of water, and that they form great submarine mounds of coral rock of that thickness; this coral rock having been slowly secreted from the waters of the sea by successive films of animal matter, each film living near the surface, while the original rocky base on which the reef grew was gradually depressed. Thus the time required for the accumulation of the larger coral reefs, like that requisite for the piling up of the larger volcanic mountains, must be very great.

Neither is this wonderful action confined within small spots. In the Pacific Ocean there is a band of groups of Atolls, which, measuring from the south end of the Low Archipelago to the northern termination of the Marshall Islands, is 4500 statute miles long, and varies from 200 to 600 miles broad, to which may be added the Caroline and Pellew Archipelagos, stretching more than another 1000 miles to the westward. The Barrier reefs on the north-east coast of Australia are 1250 statute miles in length, and from 10 to 90 miles in width. The Laccadive, Maldive, and Chagos groups, in the Indian Ocean,

stretch along a line 1500 miles in length, the Maldives themselves being 470 miles long by 60 in breadth.

The fine calcareous mud derived from the waste of these reefs is doubtless spread far and wide around them in the depths of the adjacent seas. I can at all events answer for the fact that wherever deep soundings were taken in H.M.S. Fly, between Torres Straits and Singapore, the "bottom" consisted of a fine nearly impalpable greenish mud that was almost entirely soluble, with effervescence, in dilute muriatic acid, and therefore consisted chiefly of Carbonate of Lime.

Within the tropical seas of the present day, then, vast masses of Limestone, equal in bulk to any found upon our present dry continents, are in process of formation by the action of animal life, secreting and solidifying the rock from the waters of the Ocean in which it was previously dissolved.

Foraminiferous Limestone.—Although the warmer parts of the Equatorial regions seem to be now the chief manufactories of Limestone, they are not the only ones.

The Deep Sea soundings carried out across the North Atlantic, by the officers of the United States Navy and our own, and more recently by Dr. Carpenter and Professor Wyville Thomson, have made us acquainted with the bed of that Ocean more completely than any other. Stretching from the west coast of Ireland, the bed of the Atlantic, after one or two undulations, slopes down at an angle of about 6° to a depth of 1750 fathoms, and there is then a great submarine plain stretching across till we approach the shores of Newfoundland,

when the bottom slopes up again till it rises above the water into dry land. Towards the south-east, Newfoundland is separated by a submarine valley from a plateau of rock that rises, not into dry land, but up to within 40 or 50 fathoms of the surface, and forms the well-known Banks of Newfoundland. The water over these banks, like all shallow and rocky parts of the Ocean, abounds in fish, few of which live in the deep water of the Ocean. South of the banks the bottom of the Atlantic sinks down to a depth of 5000 fathoms, or 30,000 feet, forming the deepest hollow known north of the Equator; but in all the space between Newfoundland and Ireland, and from the Azores to Greenland, no part seems to be deeper than 2400 fathoms, or 14,400 feet.

Specimens of the matter at the bottom were brought up by the sounding machines during the various surveys, and that which was found over all the central space between Ireland and Newfoundland, and as far south as the Azores, is described by Captain Dayman, R.N., as "a kind of soft mealy substance, which, for want of a better name, I have called *Ooze.* This substance is remarkably sticky, having been found to adhere to the sounding rod and line through its passage from the bottom to the surface, in some instances from a depth of more than 2000 fathoms."—(Captain Dayman's *Deep Sea Soundings.*)

Professor Huxley examined this "ooze," and says that "when a little of it is taken out of the bottles and thoroughly dried it becomes white, or reddish white,

and (though less white) closely resembles very fine Chalk, and fully nine-tenths, as I imagine, by weight of this deposit, consists of minute animal organisms called Foraminifera, provided with thick skeletons composed of Carbonate of Lime. Hence when a dilute acid is added to the mud, a violent effervescence takes place, and the greater part of its bulk disappears."—(*Ibid.*)

More than three-fourths of the Foraminifera were found to belong to one species of a genus called Globigerina, the rest being comprised of other species, except about a tenth of the whole mass, which was formed of siliceous matter, either minute particles of quartz or fragments of siliceous spiculæ of animal or vegetable organisms (*Diatomaceæ*).

The recent investigations of the Challenger expedition (1874-5) have shown that the bottom of the South Atlantic is also covered by this white ooze, but that it does not extend beyond a certain average depth. Professor Wyville Thomson states that at about 2400 fathoms the bottom deposit is generally a soft grey ooze, while at still greater depths the calcareous formation gradually passes into an extremely pure red clay, which consists almost entirely of a silicate of the red oxide of iron and alumina. He suggests that this mud is the insoluble residue left by the removal of all calcareous matter from the Globigerina ooze, in consequence of the excess of Carbonic Acid present in the bottom waters at such depths.

Dr. Carpenter is inclined to believe that the

chambers of the Globigerina were first filled with either a green or ochreous silicate of Iron and Alumina, allied to Glauconite, and that the disintegration of this, by the same agency which dissolved the shells, produced the red mud which Professor Wyville Thomson describes.—(*Proc. Roy. Soc.*, No. 159.)

We know at any rate that the green grains in many greensands, both of recent and ancient date, are only the internal casts of Foraminifera, the sarcodic bodies of the animals having been replaced by Glauconite, and their shells subsequently removed either by abrasion or solution; it is also a noticeable fact that such greensand and red-rock are found at the base of the great Chalk formation of Western Europe.

Later soundings in March 1875, at the depth of 4·574 fathoms, disclosed a bottom of gritty reddish-brown clay, which proved to consist largely of the Siliceous tests of Radiolarians. It is believed, therefore, that the red clay beyond depths of about 3000 fathoms begins gradually to alter again by the increasing proportion of Radiolarian tests, until at extreme depths it passes into this "Radiolarian Ooze," contrasting with the "Globigerina Ooze" in being siliceous instead of calcareous.

We thus see that not only is there a wide-spread deposit of Chalk now in process of formation over a large part of the Atlantic basin, of a similar nature to that which occupies so large a portion of the continent of Europe,—but that even beds of Glauconite, argil-

laceous and siliceous matter, may owe their origin to the same organic agencies.

Limestone Rocks.—If we combine the information attained up to this point, and allow that in former ages of the world animal life could secrete from the waters of the ocean as much calcareous matter as animal life is now secreting, and that movements of elevation and depression like those now in progress may have acted through an indefinite lapse of past time, we shall have no difficulty in arriving at the conclusion that the great beds of limestone we now find high and dry above the sea, or even on the summits of our mountains, may have been formed by marine animals, possibly near the surface, or possibly at great depths in the ocean. In former times the kinds of coral which make our present reefs may not have existed, but other creatures may then have lived which secreted Carbonate of Lime in equal abundance. Almost all limestones do in fact contain the bodies of Foraminifera or other animals in a recognisable form. The limestones of former times are not, however, always like coral rock, for not only were the animals different, but as Carbonate of Lime is so soluble a substance, all limestones may become greatly changed in course of time by the percolation of water dissolving and redepositing it, making it more compact or more crystalline; and other influences may be at work in producing similar changes in it.

Different limestones then, deposited at different periods of the Earth's geological history, may have differed originally from each other, and they may have

been afterwards subjected to different modifying influences, such as water, heat, and pressure, the action of which will be described in Chapter XIII.

For all these reasons a rock composed of so impressionable a mineral as Carbonate of Lime will naturally have many varieties.

The principal varieties of Limestone actually found on the dry land are—*Chalk*, a well-known soft friable variety; Ordinary *Compact* or *Crystalline Limestone*, with a great range of difference in colour and texture, hardness and purity; *Oolite* or roe stone, formed of little globules like the roe of a fish, the result sometimes of a concretionary action, sometimes of concentric deposition round minute nuclei, as described on p. 70; *Statuary Marble*, a fine even-grained crystalline limestone with a texture like loaf-sugar.

When limestone contains Carbonate of Magnesia it is called *Magnesian Limestone*, or *Dolomite*, the latter name being generally applied to a nearly equal mixture of the Carbonates of Lime and Magnesia.

Flint and Chert.—Many limestones contain siliceous concretions, as the Flints in Chalk, and the Chert in other Limestones. These were evidently formed in the rock soon after the deposition of its materials, the siliceous matter probably owing its origin to the silica secreted by minute marine animals (*Polycystinæ*) or vegetables (*Diatomaceæ*), and being separated from the surrounding material by the agency of decaying organisms, such as sponges and sea-urchins, so as to form concretionary nodules and seams, in obedience

to certain chemical laws which are so commonly in action, but as yet so little understood.

Formation of Coal.—We have not yet arrived at quite so clear a conception of the method of formation of Coal as we have of that of Limestone, but the following considerations will suffice to convince us that it is all derived from vegetables which grew upon the surface of the earth, either on dry land or in marshes, or beneath the water.

Peat.—Any one who visits the Bogs of Ireland, the Mosses of the North of England and Scotland, or the Fens of Cambridge and Lincoln, may see one step in one kind of process of the transformation of living plants into coal.

On the surface grows the green living moss with many other plants. Two or three inches below that is a brown spongy mass, consisting of the fibres of dead plants; this passes gradually down into a compacted brown mass in which the vegetable tissue begins to disappear. Lower down it is still denser and darker, and all obvious traces of fibre and tissue perhaps are lost; until, at a depth of sometimes 30 feet, a compact black substance is found which cuts like cheese, but, except from its dampness, might be called soft coal.

Some of these peat-bogs spread for many miles, and when cut away dry gravel is found beneath; the peat-bog growing gradually so as to extend itself over the adjacent ground, and sometimes rising in the centre with a gentle slope to heights of 20 or 30 feet above it, like a great rough black and brown sponge.

When artificially dried and compressed it makes a hard black substance that scarcely differs either in appearance or composition from some varieties of pit coal.

If therefore any thick bed of peat were to be depressed beneath the sea, and covered with great beds of sand or mud to a thickness of several hundred feet, it cannot be doubted that the peat would be converted into coal.

Lignite.—It is not, however, moss or peat only that undergoes this change; for in many places great fragments of trees have been found buried in the earth, retaining their external form and their woody fibre, but changed into a brown cheesy substance, or even into a quite black and brilliant coal. This substance is called Lignite, and where considerable beds of lignite are found, as in the neighbourhood of Bovey Tracey in Devonshire, the passage of a true lignite into genuine coal, and the alternation of one substance with the other, are obvious to the eye.

Coal.—If to this it be added that in the majority of instances beds of sand and clay, including beds of Coal, are full of the remains of vegetables, that many beds of Coal show on the surface when freshly exposed a mat-work of vegetable branches and stems, and that pieces of Coal when examined with the microscope show vegetable tissues and cells, the argument in favour of the vegetable origin of Coal becomes complete.

The kinds of fossil plants found about many Coal beds are indeed strange to our eyes, and not of the same species as any now living on the globe; but many

can be shown to have belonged to some kind of fern, and others have more or less analogy with existing plants. Under many beds of Coal indeed a peculiar kind of root is found in great abundance, very similar in appearance to the roots of our Water Lilies, as if the plants that formed the coal had grown in water. The ferns, however, and the coniferous plants, obviously grew upon dry land.

The vast thickness of the beds of sand and clay which are interstratified with the beds of Coal, amounting in some places to several thousands of feet, and the beds of Coal themselves, which, even if formed under water, could not possibly have been formed in water of such depth, combine to prove the fact of great successive and gradual depressions having taken place during the period when these layers of vegetable matter were being buried.

We must, then, look to plants as affording the supply of Carbon, derived from the Carbonic Acid of the atmosphere by the chemical action of vitality, which is now stored up in our Coals. Plants, as was before remarked, consisting of Carbon, Oxygen, Hydrogen, and a small quantity of Nitrogen, suffer decomposition when buried in the earth, giving off more and more of their gaseous materials in the form of Carburetted Hydrogen (the fire-damp of colliers), Carbonic Acid (the choke-damp of colliers), and water; the abstraction of these materials leaving the residue richer and richer in Carbon. This action would cause a regular gradation from Peat and Lignite to Cannel or Candle Coal, ordi-

nary Pit Coal, and Anthracite or Stone Coal, and ultimately to Graphite or Plumbago.

Coal is very commonly divided into *bituminous* and *non-bituminous*. Bitumen is a general term for certain Hydrocarbons, some of which are fluid, as *petroleum*, others solid, as *asphalt*, and the latter are soluble in alcohol. No coal, however, contains any actual soluble bitumen, though it may contain the constituents of it; thus those coals which have less Carbon and a greater proportionate amount of Hydrogen and Oxygen in their composition would be termed bituminous coals; whilst those which have lost a greater quantity of the latter in the form of Carburetted Hydrogen and Carbonic Acid, leaving behind a larger proportion of Carbon, may be called non-bituminous coals.

Varieties of Coal are also formed by the greater or less percentage of Ash which they contain. This we may look on as a clayey matter originally mingled with the plants at the time of their deposition. The greater or less quantity of ash makes the gradation from Cannel Coal or ordinary Pit Coal to a mere bituminous or more properly carbonaceous, shale or batt. An ashy coal ceases to be Coal, and becomes Carbonaceous Shale, when it is no longer able to support combustion or make a fire of itself.

Many shales are highly impregnated with true bituminous matter, and are largely used in the manufacture of Paraffin Oil; this is generally of vegetable origin, but Dr. Sterry Hunt is of opinion that the petroleum rising in the oil wells of North America is derived from

the animal matter which belonged to the numerous fossil shells and corals which the rocks contain.—(*Am. J. Sc. and A.*, March 1863.)

LIST OF ORGANICALLY-DERIVED ROCKS.

Calcareous .	Limestone and its varieties—Compact, Crystalline, Chalky, Oolite, and some Dolomites.
Arenaceous .	Greensand, Radiolarian rock, Flint and Chert.
Carbonaceous .	Peat, Lignite, Coal, Anthracite, Graphite.

Note.—Besides the above mentioned rocks there are other deposits, occurring as rock-masses, which are chemically though not organically formed ;—such is *Travertine*, or the river-limestone described at the beginning of the chapter. *Gypsum* or Sulphate of Lime often occurs in bed-like masses, and is frequently associated with *Rock-Salt*, or Chloride of Sodium, which sometimes forms beds 60 or 100 feet thick, the mineral being either colourless or having various shades of red, blue, or yellow. Both substances probably owe their origin to the evaporation of inland seas or lakes.

CHAPTER VII.

MECHANICALLY FORMED ROCKS

OR

ROCKS FORMED FROM THE BROKEN MATERIALS OF OTHER ROCKS.

By far the largest masses of the rocks that constitute the external crust of the globe are made up of the broken materials of other previously existing rocks, re-arranged by the mechanical action of moving water. It is most important then to learn how these materials were acquired.

Meaning of the word Rock.—In the first place, however, it is necessary to understand what geologists mean by the term rock. In ordinary language a rock means a hard and massive stone, but geologists know that the character of hardness is an accidental one. The very same beds of limestone may be soft Chalk in one place and hard Marble in another. The same beds of clay may be harder than the hardest brick in one place, and soft enough to mould into bricks in another. The same beds of sandstone may be hard grit in one part, while in another they could be dug out with a spade. Geologists apply the word "rock," then, as a general

term, to any considerable mass of earthy matter, whether hard or soft, or whatever may be its form or character, provided it be of sufficient importance to be spoken of as a constituent part of the crust of the Earth.

The Nature of the previously existing Rocks.—We have already examined the Igneous rocks proceeding from the interior of the Earth, and the fragmentary matters which are derived from some of them during their eruption—from those, namely, which really were erupted, or actually ejected on to the surface. We saw that all Igneous rocks are essentially siliceous, some of them, especially the Granites, containing pure Silica in the form of quartz granules, and all of them containing Silicate of Alumina. Now, almost all sands are formed of grains of quartz, and pure clays consist of Silicate of Alumina combined with water. All clays and sands, then, and all rocks made of clay and sand, may obviously be derived from the destruction and wearing down of the Igneous rocks, and there is in fact no other primary source for them, if we trace them back to their origin.

The pebbles and shingle and round stones which we find on a sea-beach are obviously pieces of rock that have been worn and rounded by the action of moving water. The sand is just as obviously the result of this grinding action still farther carried out, and there is every gradation from a coarse sand to a fine sand, and from that to a silt, and thence to the finest mud. When mud contains much Silicate of Alumina, it becomes plastic and forms clay.

All the sandy (or arenaceous) matters, then, and all the clayey (or argillaceous) substances that are most commonly met with, are the result of the erosive action of water upon previously existing rocks, which must either have been Igneous rocks, or must themselves have been derived originally from some Igneous rock. There may, however, be some mixture with the detritus from Organic rocks, and the simultaneous erosion of Limestone would of course cause the Clay or Sandstone to be more or less calcareous.

The processes by which the materials of new rocks are prepared may be considered under two heads—1. Subaerial Agencies, comprising (*a*) the air, (*b*) rivers, (*c*) glaciers; 2. Marine Agencies.

I. Subaerial Agencies.

(*a.*) *The Air, Rain, and Frost.*—As soon as any land rises above the sea, rain must occasionally fall on it, and in running over the surface must commence to wear it away. If the rock contain lime, either as a silicate or a carbonate, the carbonic acid of the atmosphere and of the atmospheric waters continually tends to dissolve this lime, and thus to loosen the particles of the other substances which the lime held together. If the rock be pure limestone its surface is always in process of complete solution, the carbonate of lime being all carried off by rain water, hence such rocks never yield any soil, but are bare and barren.

The action of the wind even, combined with the alternations of wet and dry upon the surface of the rock,

produces some effect in decomposing and wearing away its surface.

Great and sudden variations in temperature also, causing the rocks to expand and contract rapidly, effect their disintegration even in countries where little rain falls, as in the interior of Africa.—(*See* Livingstone's *Zambezi*, pp. 492-516).

Two very good instances of the action of the atmosphere on Granite rocks may be found in the first part of the tenth volume of the *Journal of the Geological Society of Dublin.*

The first is in a paper by Mr. T. W. Kingsmill on the Geology of the East Coast of China. In describing the Granite of the mountains near Canton, he says: "This Granite, wherever it occurs, has been deeply disintegrated, sometimes to a depth of 100 or 200 feet, whilst everywhere, imbedded in the soft, yielding matrix, there occur nodules, of more quartzose character, which have resisted the effects of time and chemical change. The original quartz veins of the granite, broken into small fragments, still traverse the disintegrated mass in all directions.

In the same number of that Journal there is a paper by Captain Meadows Taylor on the Geology of the Shorapoor district in Central India, in which he figures and describes some most extraordinary masses of granite, forming fantastic columns and piles of rounded blocks, of all sizes up to 50 feet in diameter, some of the piles being more than 100 feet in height; the blocks having evidently been left in this position by the

gradual waste of the surrounding rock under the influence of the rain.

I have seen similar perched blocks in the tropical parts of the N.E. coast of Australia. The logging or rocking stones of Cornwall and other places are the result of the same natural action. Granite is decomposed *in situ* into a mere sand, so that it could be dug out with a spade, in several places in Ireland, in Leicestershire, and in Brittany. On the summits of ridges and on steep slopes the grains are washed down by the rain as fast as they are loosened from the blocks, leaving only the hard crags above.

All rocks are of course subjected to this disintegrating and degrading action of rain-water, but the amount of soil produced varies with the kind of rock which is acted upon, and also depends on the contour of the land; on sloping ground it is gradually washed downwards, so that in some valleys and "bottoms," where it is not carried off by streams, considerable deposits of "*wash*" or *brickearth* are sometimes accumulated.

In extra-tropical regions, or in lofty land within the tropics, ice becomes no mean agent in the breaking up of rocks; for as water expands on passing into ice, it is obvious that if the pores of a rock, or its joints and crevices, are saturated with water, and that water freezes, a great mechanical power is called into play, either in disintegrating the particles or in loosening the blocks of the rock.

Even when rain water sinks beneath the surface it often plays an important part, both chemically in dis-

solving calcareous rocks, and mechanically in widening the joints and crevices of all rocks. The latter action is often most marked where the water issues again in the form of springs. A line of springs along the foot of a cliff or steep bank, either on the sea-side, or in the interior of the country, will often so far undermine the rocks above, that after some heavy rain, or sudden thaw, a large mass of them, a mile or two in length, and one or two hundred yards in breadth, shall be launched forward in what is called a "landslip." A heap of ruins is thus formed, which is much more easily acted on than while it formed part of the solid rock, and the materials are then removed by the sea or by the neighbouring streams. "Landslips" are also produced by earthquakes, which cause great pieces to slide from the steep sides of valleys. In both cases the streams running down the valleys are sometimes blocked for a time, and perhaps made into lakes, and a head of water thus accumulated, which, when the dam gives way, affords a far more destructive water-power than that of the mere stream. Temporary lakes are also formed in Alpine regions by the fall of avalanches into valleys, blocking up the streams, and accumulating a quantity of water, which, when the ice-barrier is suddenly removed, carries everything before it for miles down the valley.

(*b*) *Rivers and River Valleys.**—The dry land may be parcelled out into separate "basins of drainage," divided from each other by "watersheds," or lines

* For a clear and concise view of this subject, see an excellent little work entitled *Rain and Rivers*, by Col. G. Greenwood, 1857.

from which the rain water runs each way, and which no running water crosses. A "basin of drainage" is a district all the waters of which drain towards one main artery or central river issuing by one mouth into the sea. That mouth, however, in some rivers, becomes so much encumbered by the deposition of the fine earthy matters brought down by the river, that these muddy materials rise above the water, and the river is extended beyond its original termination by two or more fresh-water channels through the muddy deposit, which is then called a Delta.

A river is formed by the union of a number of tributaries, each of which is made up of brooks, and rivulets, and lesser streams; but it is usual to select one of the streams, generally the one most remote from the mouth, and to look upon that as the origin of the river, and some large spring at the head of that is sometimes pointed to as the *source of the river*. This, however, is a mere arbitrary selection of one stream from the rest. All rivers consist of the superfluous rain-water or melted snow that falls upon the area of the basin of drainage, beyond that which is carried off by evaporation, and are large therefore in proportion to the extent of the area and the amount of the rainfall on it. When a part of the main watershed of the basin rises on to a mountain range lofty enough to be covered by perpetual snow, the supply of water becomes most constant, because hot sunshine, which would otherwise cause the streams to shrink, melts the snow, and thus compensates for the want of rain.

A basin of drainage, then, and its resulting river, are the effect of a regular systematic operation upon a certain area, the mode of which must be capable of discovery, and therefore of description. The operation, however, although regular, is yet complex, so that it is difficult to give such a general account of it as shall be applicable to all places, but I will attempt a slight sketch.

Suppose a land commencing to rise above the sea, the ridge of a mountain chain, or that which afterwards becomes or discloses a mountain chain being the first part to become dry land. We may suppose this mountain chain to have been previously prepared below the surface in the crust of the earth, its beds having been bent up into folds, so that it is made of many long and often thick layers, of different constitution, and lying in very various positions, but all the parts running generally parallel to the length of the chain. The subterranean disturbing action that has thus tilted and bent the beds which ultimately form the mountain chain may be altogether separate in time and effect from that which afterwards lifts up the whole area above the sea. Every part of this land suffers, as it rises, from marine erosion, which leaves the crest of the mountain chain much indented perhaps with sea-formed crags and pinnacles in some parts, and sea-formed valleys or hollows in other parts. These hollows exist for a time as straits or sounds between the islands formed of the rising mountain peaks, and the deepest of them afterwards become "passes" or "gaps." As the

elevation goes on, and the mountains are gradually lifted altogether above the sea, the islets are connected into one island, and eventually the summits of the lower hills appear, and lastly the plains and flat lands. But during this process of elevation, the erosive action of the atmosphere and the cutting power of the streams are constantly at work, commencing first upon the mountains, and then extending to each piece of lower ground as it is laid dry. Had the sea alone acted on the rising land, we should have had smooth or gently undulating slopes upon the hills, and long sweeping undulating plains over the rest of the country. The hollows of the undulations would be over the spaces where the present valleys are, for it was doubtless the existence of these sea-formed undulations that determined the course of the superfluous rain-water when it began to flow over the land; but had it not been for the action of this rain-water the valleys would never have been worn to anything like their present depth, nor the slopes of the hills, especially those towards the interior valleys, have acquired anything like their present steepness.

The first streams formed on the flanks of the rising mountain chain would run directly off down the slopes from the crest into the sea. These would begin to form those valleys which are called the lateral valleys of a mountain chain. As soon as they became a little deep, other small streams would flow into them from their sides; and these, acting on the softer or more easily destructible bands of rock that run parallel to

the length of the mountain chain, would commence the formation of the longitudinal valleys of the mountain chain. The lateral valleys then would be the primary or first eroded river valleys, and the longitudinal would be the secondary valleys. The primary or lateral valleys, being due, in the first instance, to the comparative steepness of the slope of the original flanks of the mountain chain, giving an impetus to the streams, would be worn directly across all the bands of rock that run parallel to the length of the chain, independently of their hardness or softness. No stream could cut its channel in any soft band in the higher part of its course below the level of the channel in the next hard band of the lower part of its course. Its channel, however, would naturally be more narrow, and its sides more steep and precipitous, in the parts where it cut across a hard band than where it traversed a soft one. The softer and more easily eroded banks of the stream would always be apt to slide down the slopes, and the valley would widen there accordingly. Moreover, the longitudinal valleys, originating in these soft or easily destructible bands, would be wider and more regular than the lateral valleys, and if a soft band was very wide, and continued for many miles along the length of the chain, it is quite possible that the longitudinal valley formed in it, although originally a mere tributary to the lateral valley, and caused by a stream commencing to drain into that valley, might ultimately be worn back along the soft band, so as to be not only wider but far longer than the upper part of the

lateral valley which lies above the junction of the two. Such a longitudinal valley would be likely to bring a greater volume of water from a greater distance than the upper part of the lateral valley itself might bring. In such cases the stream running down this longitudinal valley would be very likely to be considered the main head water of the principal river, and some little brook or spring towards the head of that valley be called the source of the river. We have already seen, however, that the term source is quite inapplicable to any head of a river, even in its present state, and it becomes still more inappropriate when we know the history of the formation of a river.

Where the rivers quit the mountains and issue on to the plains, we lose the distinction between the lateral and longitudinal valleys. Still the influence of the same circumstances—namely, the comparative hardness or destructibility of the different masses of rock cut through, or approached or avoided by the river—may be traced both in the direction and in the varying forms of the valleys.

The result finally arrived at is, that the removal of all the mass of rock that originally intervened between the former sea-formed gently undulating surface and the bottom of the present glens, ravines, and valleys, is due entirely to the action of atmospheric erosion—the hollows have been worn and the materials carried off by the brooks and rivers that now run down them.*

* [In Jukes' *Manual of Geology*, 2d edit. p. 105, 3d edit. p. 451, a description will be found of the tide receding from a

When at length a great river reaches the broad plains which are but little above the level of the sea, its current must necessarily slacken, its erosive force consequently depart, and its carrying power diminish, so that it deposits even the fine materials which it brings down.

These plains are like the alluvial flats in the higher parts of its course, where obstructions make it sluggish, and a similar deposition takes place; but as the river has in the plains no longer any valley sides to confine it, it will, if left to itself, shift its channel from time to time, so as perhaps to wander over many parts of the plains. When, however, man takes possession of these plains, these shiftings of the river channels, and the overflowing of their banks, incommode his operations, and he endeavours to prevent them by artificial banks. But as he cannot prevent the river from bringing down earthy matter, the raised banks merely cause the mud to be deposited in the bed of the river, so that the height of the banks must be continually added to. For this reason, the rivers which traverse the fens of Cambridge and Lincoln shires are in some parts at a height of several feet above the level of the corn-fields, and the drainage has to be pumped up into the rivers instead of running down into them. In like manner the surfaces of the Po and the Adige in North

flat muddy coast, and producing the miniature representation of the river system of a great continent. Any one can watch this for himself, and the foregoing description, in which a country is supposed to be first engraved into hill and valley, will then be much better understood.—Ed.]

Italy are in some places on a level with the roofs of the houses—the rivers running along great embankments, as if they were aqueducts.

If space permitted, it would not be difficult to follow the course of one of our British rivers from the mountains to the sea, and describe in detail the marks of its erosive action on its banks, and show how it has deepened and widened its own bed, and how the shifting of that bed has contributed to excavate the valley. My colleague, Mr. Geikie, has given a graphic sketch of this action in the ninth chapter of his interesting little book called the *Story of a Boulder.*

In other parts of the world, however, this action may be traced on a far grander scale. In the central region of the Alps the valleys of the Rhine and the Rhone are conspicuous instances of it. Charpentier long ago showed that the Pyrenean valleys were also formed by the rivers that traverse them. Dr. Dana did the same for the wonderful network of gulleys that furrow the slopes of the Blue Mountains of New South Wales, and having myself viewed a part of that district, I can record my complete agreement with him. The same author assigns a similar origin to the deep valleys and gorges that radiate from the high volcanic islands of the Pacific, separated, as they often are, by mere knife-edged ridges of rock, with steep and sometimes perpendicular sides. Having ridden over some of the volcanic mountains of Java, along sharp crests between profound valleys, which were even wider at bottom

than they were deep,* and noted that the cones were furrowed by these radiating ravines precisely in proportion to their age, the newest of all being still smooth and uneroded, I can here also venture to corroborate him.

The most wonderful instances, however, of the erosion of valleys by rivers are those which are so beautifully depicted in the plates given in the Report of the Exploration of the Colorado River of California under Lieutenant J. C. Ives, in 1857-8.†

Dr. Newberry, the Geologist of the expedition, gives an excellent account of the structure of the country examined. The great ravine (or cañon) of the Colorado is 300 miles long, and varies from 3000 to 6000 feet deep, with only just room enough at bottom for the water of the river, and with sides that rise like great walls from the river to the plateau above. This ravine and those of the numerous winding tributaries to the river, have been cut down through horizontal beds of hard limestone and other rocks belonging to the Carboniferous and older periods, and into the Granite which lies below them. The Granite is in some places cut into to a depth of 1500 feet, and some of the hard siliceous limestones above it have an aggregate thickness of 1000 feet. All

* Showing that these valleys could not have been caused by cracks in the earth's surface, but must have been formed by erosion.

† The Senate of the United States ordered ten thousand extra copies of this work to be printed in the year 1860. I cannot help here contrasting this order with the utter indifference exhibited by our own governing bodies to the publication of the results of the scientific explorations of our own officers.

the beds are quite horizontal and undisturbed, and it is evidently to this circumstance that the perpendicularity of the walls of the ravines is due; had the beds been inclined they would have slipped into the valleys, and the same thing would have happened had they been traversed by oblique fissures or lines of fracture.

Our own river valleys and those of other parts of the world are wider and more irregular in form, in consequence of the variously inclined positions into which the rocks below them have been thrown, and the differently constituted masses of rock that are brought up to the surface in different places, so that the cutting down of the river channels produced a corresponding variety of effect in the forms of the valleys.

Deltas.—In tracing a river from the mountain to the plains, it would be found to be always active in carrying down earthy matters from a higher to a lower part of its course. The size of the fragments is necessarily proportioned to the strength of the current. Large boulders are rolled along by mountain torrents, pebbles by rattling brooks or swift streams, but when rivers become navigable, they rarely carry anything coarser than sand, and where they traverse great plains nothing but fine mud. Fresh pebbles, however, are continually made by the breaking up of the boulders, fresh sand by the grinding of the pebbles, fresh mud by the trituration of the sand, so that the supply is never-failing.

When a river traverses a lake, it makes a flat, commonly a delta, at the part where it runs in, deposits all its earthy matter in the bed of the lake, and issues

as a stream of clear water, a character it will maintain for some distance until defiled by muddy tributaries that have not passed through lakes.

When a river issues into a sheltered bay of the sea where its mouth is not swept by strong currents, it naturally deposits all its materials where its own stream is checked by the sea, and forms a delta there. Some of the larger deltas of the world give us a certain measure of the amount of work done by the river. The deltas of the Po and Adige and the neighbouring streams are now united, and form a flat 100 miles in length, which is known to have grown from two to twenty miles in width during the last 2000 years. Adria, which was a seaport in the time of Augustus, and gave its name to the Adriatic Sea, is now twenty miles inland.—(Lyell's *Principles*, chap. xv.) But this river deposit has filled up the old sea-margin in spite of the fact that the bed of the sea has suffered from depression. M. Degoussée sank an Artesian well at Venice, which in 1847 was 432 feet deep, without having reached the bottom of the deposit. Moreover they passed through, in this sinking, beds of turf at 95, at 155, at 275, and at 410 feet, showing old land surfaces, with vegetation similar to that now flourishing on the present surface, at these successive depths, those old land surfaces having subsided and been covered by fresh deposits.—(*D'Archiac*, vol. ii. p. 232.)

The Delta of the Nile runs for 200 miles along the coast, and its head is 100 miles in the interior. That of the Ganges is far larger, for, with the conterminous

delta of the Brahmapootra and intermediate rivers, it makes a coast-line of more than 200 miles, and a flat which is 100 miles wide at a distance of 250 miles in the interior, its whole area being probably 50,000 or 60,000 square miles. It was bored for an Artesian well at Calcutta to a depth of 480 feet, the well penetrating some old land surfaces at several depths, proving former depression, and also beds of gravel, which likewise indicate a more rapid current formerly, and, therefore, most likely a higher level for the land (*Lyell*). There is probably round the head of the Bay of Bengal enough river deposit to cover all England and Wales to a depth of 200 or 300 feet. The Delta of the Mississippi has an area of 13,600 square miles, and carries the river out by a natural canal for a distance of about 800 miles into the Gulf of Mexico. A well was sunk in it to a depth of 600 feet north of New Orleans, without reaching the bottom of the deposit. The Delta of the Orinoco seems to be as large as that of the Nile, but the rivers Amazon and La Plata have no real delta, a circumstance attributable to the strength of their currents, which according to the accounts furnished by the Admiralty, may be felt at a distance of several hundred miles from their mouths (*Admiralty Manual of Scientific Inquiry*, note, p. 24), and to the oceanic currents that sweep past them. Vast clouds of fine mud must be annually poured out by these rivers into the South Atlantic Ocean, and may float far and wide before they settle in the deeper parts of its bed.

If we come nearer home in search of examples, we

may point to Holland as the conterminous delta of the Rhine and other rivers, and made of mud brought down from the Alps and the other mountains of France and Germany; and lastly to the wide fens of Cambridge and Lincoln as the conterminous delta of the Cam, the Ouse, the Nene, the Welland, and the Witham rivers.

(c) *Glaciers and Icebergs.*—In high latitudes, as in Greenland or South Shetland, the water precipitated from the atmosphere is all frozen, that is, it falls as snow instead of rain. This is what occurs even in the Torrid Zone wherever the land exceeds an altitude of 15,000 or 16,000 feet above the sea, and in all other latitudes, at a less height in proportion to their distance from the Torrid Zone. In the Alps the snow-line in summer occurs at a height of 8000 feet above the sea. About the North and South Poles it comes down to the level of the sea. As in regions of perpetual snow even the hottest summer's sun fails to melt all the snow that falls in a year, it follows that there must be a continual accumulation of it, and, if there were no way of getting rid of it, all the water in the world would be eventually transferred to these regions and remain there in a solid form. This is prevented, however, by the conversion of the lower part of all perpetual snow into ice, partly by the pressure of the superincumbent mass, and partly by the percolation of water, derived either from the occasional melting of the surface by the sun, or from still rarer rain showers. This ice then slips and slides over the sloping rocks beneath, until, in high latitudes, it is pushed into the

sea, or in warmer districts it melts away in the valleys below. These moving ice masses are called Glaciers, and the portions which are broken from time to time from off the margins of those glaciers that end in the sea are called Icebergs.

All the interior of Greenland is covered by one enormous glacier of great thickness, constantly added to by every fall of snow, and always giving off icebergs to the sea. On the west coast of Greenland great glaciers are described by Dr. Kane and Dr. Rink, some of them extending for as much as 60 miles along the shore, and spreading out to sea for many miles in front of it, so that it is impossible to reach the land. Some of the glaciers of Greenland are 2000 feet thick, and the ice region is believed to be 800 miles wide, almost all of it sliding off towards Baffin's Bay. The icebergs derived from its edge are sometimes many miles in extent, with cliffs rising from 100 to 200 feet above the sea, involving a thickness of nine or ten times that amount below water.

The glaciers of the Alps are sometimes as much as 600 feet in depth, and they fill the valleys for many miles below the snow-line till they come down to a level of about 4000 feet below it, where they terminate, in consequence of the ice melting into water and proceeding as a brook or a river.

As may be easily supposed, the sliding of such enormous masses over the surface of the rocks grinds and polishes them and wears them away; stones frozen into the base scratch and groove the rocks, and the

result is the production of a quantity of fine powder or mud, of which all glacier rivers are as full as the water from a stone-mason's yard when sawing and polishing are going on. A lump of glacier ice dissolved in a tumbler of water makes it as turbid as a spoonful of milk would. This proves that the glaciers exert a greater erosive effect on the sides and bottoms of the valleys than the rivers, since no rivers are so continually muddy as those which proceed from glaciers.

Glaciers bring with them, moreover, not only mud and sand, but blocks of all dimensions. Wherever a glacier passes beneath a crag or cliff of rock it receives on to its surface a continued supply of blocks derived from it, and carries them forward in its course. A line of such blocks may generally be seen on each side of a glacier. When, however, two glacier valleys meet and coalesce, the two streams of stones on their adjacent sides must also coalesce, and proceed together below the point of junction down the middle of the glacier below. As a large glacier, like a river, is made up of the union of many smaller ones proceeding from different valleys above, the lower part of it is often covered with many streams of stones derived from the coalescence of the numerous tributary glaciers, and these are all carried forward to the place where the glacier terminates. Here they are all thrown down in a confused pile of blocks and rubbish and dirt, which in Switzerland is called a "moraine."

The heap at the end of the glacier is distinguished as the "terminal moraine," the line of stones travelling

down its sides being called the "lateral," and those in the middle the "median moraines."

It is obvious that blocks of almost any size, and of any conceivable shape and angularity, even large flat slabs, may be thus transported along the whole length of a glacier, and such masses are seen in the moraines of the glaciers of Switzerland and of other parts of the world.

But where the glaciers terminate in the sea, and fragments of them are every now and then floated off as great icebergs, any blocks they may carry or contain will be floated off with them, and will travel with them till the icebergs dissolve, and drop the blocks to the bottom of the sea. Now some icebergs travel even hundreds of miles before they finally melt away, so that blocks of rock of great size may thus be carried far from their parent sites, and dropped on the sea bottom in places where no similar rocks have ever been formed. If, then, that sea bottom were lifted up, and became dry land, it might be difficult at first to imagine any means by which such blocks could have been carried there. This very difficulty actually occurs with respect to large blocks and boulders, now found lying many miles from their parent sites, in the British Islands, and in the north of Europe and America, and can only be solved by supposing that they have been carried by icebergs when these countries stood at a lower level, so as to be covered by the sea.

2. Marine Agencies.

Perfectly still water is evidently powerless to wear away siliceous rocks; and deep water must be more or less perfectly tranquil. The depths of the ocean may not indeed be utterly stagnant, since there may be ascending and descending currents of water throughout it, but these could exercise no abrading force, nor even any transporting power, upon the materials that lie below the water. The finest and most impalpable mud, then, when once it has settled to the bottom of deep water, remains secure from all external influence of erosion. The oceanic ooze is an instance of this security, which has been described in the last chapter.

Action of the upper surface of the Sea.—The upper surface of the Sea, however, is in perpetual motion. The winds keep up on it a continual agitation, and force it into waves of all dimensions, from the tiniest ripple to the long rolling swell, in the hollows of which even ships sink out of sight. The Sun and the Moon lift it into daily tides, which become currents when they strike upon the land; and the Sun's heat, combined with the Earth's motion, keeps up continual great currents of circulation in the Sea, which sweep slowly round the Earth, closely resembling the currents of the Air, which we call Winds.

The waves, where they beat upon the land, are the instruments of the destruction of the rocks, while the tidal and oceanic currents are the transporting powers that carry away the resulting materials. The rise and fall of the tides assist the waves by giving them a

greater vertical space on which to act, and in some cases by the frequent alternation of wet and dry upon the rocks.

Few persons have a sufficient appreciation of the power of the sea-breakers when they strike on the land, under the influence of a far-reaching and long-continued gale of wind. Visitors to the sea-side are more familiar with sheltered bays and sandy strands, than with the foot of cliffs and headlands that sink into deep water. Although I had seen the swell of the open sea in some of its most magnificent aspects in various parts of the world, and had watched the tremendous surf which roars over the outer edge of coral reefs, or thunders on the shores of South Africa and Australia, it was not, I think, until I had examined the cliffs and headlands of the west coast of Ireland, that I became fully aware of the power of the ocean to wear away land.

The hardest rocks, even those of Igneous origin, are all traversed by natural joints and crevices; and all aqueous rocks are also divided by planes of stratification. The dash of the waves soon causes moisture to penetrate into these natural planes of division, and thus loosens the adhesion of the blocks into which all rocks are divided by them. A heavy sea that rises to a height of 20 or 30 feet, and falls upon the rocks with many hundred tons of foaming water, is a battering ram of no mean power, and its blows are continually repeated at the rate of one or two in a minute; but the mere blow is not the whole of the force exercised;

when the water is dashed against the rock some of it is injected with great force into every crevice and fissure it can find; and the air previously existing in these crevices is impelled into others above and beyond them. The recess of the wave relieves this air from the sudden pressure, and both air and water are then suddenly sucked back, so as to act in the contrary direction, and still farther enlarge the fissures and loosen the blocks about them. As soon as one block is entirely removed the commencement of a cave is formed, the air in which becomes an elastic penetrating instrument set into violent action every time that a wave is hurled against its mouth, and alternately fills and empties the cavity with a violent impulse and recess. Heaps of pebbles and boulders are also accumulated inside, and are dashed about by the waves, acting like so many hammers upon each other and on the walls of the caves. In this way great caverns are ultimately made, undermining bold headlands and lofty cliffs.

When by these and other processes the foot of a cliff is undermined, so far as to reach the larger natural joints on all sides, the mass above is no longer supported, and falls in a heap of ruined fragments, which the breakers then proceed to reduce into round blocks and sand, and roll and carry away from time to time, till they lay bare the cliff again for fresh assaults. Each step in this operation may require years, or even centuries, for its completion, but it is a work for ever going on upon every exposed coast in the world. The pro-

duction of caves, however, and the consequent undermining of the rocks above, can only take place where the cliffs are perpendicular, and this depends partly upon the lie of the rocks and partly upon their power to resist atmospheric erosion. Along most of our coasts the subaerial agencies—frost, springs, and rain—work faster than the waves, and the cliffs in consequence slope backward at a greater or less angle from the shore, the sea being chiefly occupied in breaking up and washing away the fragments detached from the cliffs, thus ever leaving a fresh surface exposed to the attacks of atmospheric erosion.

Sometimes, however, both processes seem to be carried on at a nearly equal rate; on the coast of Thanet the chalk cliffs are perpendicular, but there are only a few caves, and after a storm a completely new face of cliff is often exposed by the beating of the waves on a surface previously loosened by the action of frost and rain.

Waste of the East and South Shores of England.—Where the land is composed of the softer kind of rocks, especially if the coast be swept by a strong current which can readily carry off the eroded materials, the waste of land sometimes becomes very rapid, so that all the inhabitants become sensible of it. In Sir C. Lyell's *Principles of Geology*, chapter xx., will be found a very interesting account of the destruction of land that has been going on along the eastern and southern coasts of England during the last few centuries. The sites of many villages and some consider-

able towns, along the coasts of Yorkshire, Norfolk, Suffolk, Essex, and Kent, are now beneath the sea, which has eaten away the land on which they stood.

Ravenspur, where Bolingbroke landed to depose Richard II., and other neighbouring places, are entirely gone—sands, dry only at low water, appearing in their place. The site of the old town of Cromer is now in the German Ocean, the inhabitants having continually built inland as the sea gained on them. At Sherringham harbour there was, in 1829, a depth of 28 feet of water (enough to float a frigate) at the very spot where, forty-eight years before, there stood a cliff 50 feet high with houses upon it. Churches, villages, and manors have, one after another, disappeared, so that their previous existence is only known from old records.

Dunwich, once the chief port in Suffolk, is now but an inconsiderable village, and Doomsday-book tells us of land outside it as having been taxed by Edward the Confessor, but being even *then* destroyed by the sea. In other later records mention is made of, at one time, a monastery, at another several churches, then the old port, then 400 houses at once, and gradually the gaol, the town-hall, the high roads, then of ancient cemeteries, the coffins of which were for some time exposed in the cliff—all swept away by the devouring sea. Mention is even said by Ray to be made in old writings of a wood a mile and a half to the east of the town, the site of the wood being of course now farther than that in the German Ocean.*

* It is not only in scientific books that these facts are de-

In Kent, Reculvers Church, which in Henry VIII.'s time was a mile from the sea, is now on the cliff, and would have been long ago destroyed if artificial means had not been taken to preserve it as a sea-mark.

The Straits of Dover have doubtless been worn wider by a mile or more since Julius Cæsar's time, who, if he could revisit the scene of his invasion of Britain, would be very likely as much puzzled to find the precise spots where he sailed from and disembarked at, as his commentators are in determining them from his descriptions. The view from Shakspeare's Cliff in the present century, even before the railway operations were commenced upon it, could not have been nearly so "fearful and dizzy" as it was when Shakspeare wrote. Lyell tells us there was a great landslip in 1810, by which Dover was shaken, and that another still greater had occurred in 1772.

Similar waste is going on all along the south coast till we reach the harder rocks of Devon and Cornwall, when we can only judge of it by its effects in the indented shores and rocky cliffs and islets.

The farmers and landed proprietors in many parts of the east and south coast of England reckon on a loss of land amounting to one yard per annum all along the shore. If, however, we suppose it to amount to only one foot per annum, with an average height of cliff of only 25 feet, this, along a coast of 500 miles in length,

scribed ; a graphic account is given of the destruction of the coast of Suffolk by Wilkie Collins in his novel of *No Name*, scene 4th, chap. 1st.

would give every year the materials of a bed a foot thick, and forming a square of 1½ mile in the side. It is, therefore, not unreasonable to suppose that the materials for such a bed are carried every year from the coasts of England and deposited somewhere or other on the bottom of the sea.

Plains of Marine Erosion.—This erosive action may extend to a depth of some few fathoms beneath the mean level of the sea, but cannot reach to any great depth. Its action, then, tends towards the production of a submarine flat or plain in the parts that are passed over, bounded by a line of cliffs that are lofty in proportion to the height of the land which is eaten into.

If the land were quite stationary it would ultimately be all worn away, and a shallow sea would flow over the flat where it formerly existed. Many of our present plains on the dry land have been formed precisely in this way, mountains that formerly rose over those plains having in these cases been removed by the erosive action of the waves.

It was shown, however, in Chapter IV. that the land is anything but stationary, and it follows that as it slowly rises or falls through the upper surface of the sea, every part of its own surface will be subject to this erosive action, the results of which will vary accordingly. The external action of the sea is like that of a fixed engine with a horizontal planing and graving machinery contrived to carve into any substance, and the internal force of elevation and depression resembles a vertically acting power below, raising or lowering the

substance through the horizontal cutting plane, tilting it sometimes in different directions so as to produce a very varied form in the carved substance.

Distribution of Material.—The Sea is the ultimate recipient of all eroded materials, and in the shallow seas surrounding our own Islands we may learn what becomes of some of those which are gained from the land by erosion either of the rivers or the sea. The order in which these materials are deposited must especially be noticed; a river debouching into the sea will first deposit stones and gravel, farther out sand, and last of all silt and mud; this succession is always maintained except where interrupted by currents or other local circumstances, so that pebbles and gravel generally imply shallow water and the neighbourhood of land, sand indicates deeper water, and mud usually forms the bottom of deep and quiet seas; sand and mud, however, in the absence of any strong current, are often found in shallow estuaries and bays. The Admiralty charts, like all other good charts, indicate by letters the nature of the bottom as well as its depth; and by colouring these charts with different colours, according as the bottom consists of sand or mud, we get a very instructive map of the deposits now being formed.

In the English Channel, and in the shallow parts of the German Ocean and the Irish Sea, nothing finer than sand is found below low-water mark, small stones being noted in many parts of the English Channel.

A large irregular patch of mud lies off the mouth of the Bristol Channel, stretching between the Scilly

Islands and the coast of Wexford. This is at the bottom of water varying from 40 to 60 fathoms in depth, and it is entirely surrounded by rather shallower water, the bottom of which is marked as sand. Another larger area of mud commences farther west, where the depth increases to 60 or 70 fathoms, and this leads out by a narrow lane of 80 fathoms towards the oozy bottom of the deep Atlantic. Sand, however, is found at several places off the west coast of Ireland beneath water of 100 or 200 fathoms in depth, and coarse sand with pebbles as large as nuts has lately been found by my friend Mr. Hoskyns, R.N., on the Porcupine Bank, at a depth of 80 and 90 fathoms, 160 miles west of Slyne Head, in County Galway.*

In the Irish Sea, half-way between the coasts of Wexford and Cardigan, there is a considerable area of mud in water of 50 to 60 fathoms' depth, and another small one between Bray Head and Holyhead, in a hollow varying from 60 to 86 fathoms, surrounded by sandy ground of 20 to 30 fathoms only. A long narrow strip of mud runs from the mouth of the Solway Firth down between the Isle of Man and Lancashire, lying in from 16 to 20 fathoms, the surrounding sandy bottom being generally, but not invariably, shallower. A longer and larger strip of mud lies between the Isle

* From the aspect of the sand and gravel dredged at this place, of which Mr. Hoskyns was kind enough to send me a sample, I should be inclined to doubt that it could be now in process of transport from the land. It seems more likely to have been an old drift-covered land that had been depressed beneath the sea.

of Man and Ireland, running up between the coast of Antrim and the Mull of Galloway, where the depth reaches in one part to 149 fathoms, and continues into the mouth of the Clyde as far as the water retains any considerable depth. The bottom seems always to be muddy in the central parts of the area, where the depth exceeds 60 fathoms, and sandy on the shallower slopes towards the shores. It would appear as if these sandy banks protected the mud that had sunk into the hollows from removal by the sweep of the currents.

Judging from these facts it is evident that even the large deltas found at the mouths of rivers do not give us the full account of the amount of erosion they have performed. Large portions are carried out to sea by the river itself, or by the wearing of the sea breakers on the delta. The Nile delta is said to have been prevented from enlargement, for several centuries at least, by the sea currents that sweep past it. Like all the deposits of a river valley, the rest of the delta mud is but a temporary one; frequent removal to lower parts, frequent replacement by similar matters from above, and final delivery to the ocean, is the rule of procedure. The delta and the alluvial flats of a river are like the balance which a merchant keeps at his banker's, constantly drawn upon in one direction, and as constantly replenished from the other, but never representing in amount the whole value of his transactions.

Conclusions.—Such being a brief sketch of the agencies by which rocks are continually being destroyed,

and the materials transported to the bottom of lakes and seas, there is little difficulty in comprehending how these materials are re-constituted into rocks. If the bed of a lake or a sea receive through a period of many thousands of years, or centuries, layer after layer of these materials, they will ultimately form a thickness of many hundreds and even many thousands of feet. The mere weight and pressure of the upper part of the mass will of itself consolidate the lower beds. Lime, and iron, and silica, or other substances diffused through them in a soluble state, may in some cases cement the particles together. If a thickness of several thousand feet be eventually deposited, the lower part will then acquire a higher temperature, derived from the internal heat of the earth—as mentioned in Chapter I.—and heat may aid the consolidation imparted both by pressure and by cementation. If forces of disturbance and elevation begin to act upon them from below, the pressure of these forces acting against that of gravitation will also aid it in its power of consolidation. With all these agencies brought into play, one after another, it is easy to see how soft mud or clay may be hardened into the hardest slate-rock, or how loose sand and gravel may be compacted into the firmest and toughest grit-stone or pudding-stone, even making it hard enough to take a polish.

The rocks originating in this way may be classed as the arenaceous, which are usually most purely quartzose, and the argillaceous, or those containing enough silicate of alumina to form clay.

The *Arenaceous* rocks then are sand, silt, gravel, shingle, and rubble, in their incoherent state; *Sandstone, Gritstone, Conglomerate,* and *Breccia,* when compacted together—*Breccia* being a mass of angular, and *Conglomerate* a mass of rounded, fragments or pebbles.

The constituents of Sandstone and Gritstone may cohere from simple pressure without any visible cement, although in red sandstones the pellicle of iron-oxide round each grain tends to hold the mass together; more frequently, however, like Conglomerate and Breccia, they are set in a siliceous or calcareous matrix which binds the whole into a compact stone.

The *Argillaceous* rocks are mud or clay in their soft state, *Shale* or laminated clay which splits easily into thin plates, *Marl* or calcareous clay, *Clunch* or indurated marl, *Clay-rock* or indurated clay, and finally, *Clay-slate,* which splits into hard firm plates, not, like shale, because it was deposited in thin layers, but in consequence of a structure imparted to it by a subsequent agency, as will be described in Chapter XIII.

The following list gives the above in a compendious form.

LIST OF MECHANICALLY-FORMED ROCKS.

Arenaceous	Gravel and Rubble when loose, Conglomerate and Breccia when compacted. Sand and Silt when loose, Sandstone and Gritstone when compacted.
Argillaceous	Mud, Clay, Marl, and Loam, when soft; Shale, Clay-rock, Clunch, and Slate, when indurated.

CHAPTER VIII.

SUMMARY OF THE PRECEDING CHAPTERS.

In the seven preceding chapters a slight sketch has been given of the principal physical operations which are now taking place in or upon the crust of the globe.

The amount of any one of these operations which is brought about, at any particular place, during the life-time of any one man, may be so small as to be almost imperceptible; and he may at first, accordingly, think the operation itself hardly worth regarding. This, however, would be a great mistake. We might as reasonably disregard the lapse of time, because, at a hasty glance, we could not perceive any motion in the hour hand of a clock, or the shadow of a dial.

The principal bulk of all the dry land on the globe, to a great depth beneath the surface, is formed of rock that has been accumulated, grain by grain, at the bottom of the sea. This is true also for much of the rock that lies beneath the sea itself, perhaps for almost all of it. This grain-by-grain accumulation has taken place, not everywhere at once, but piecemeal and in patches, here and there about the globe, just as our present seas and lakes are now receiving small and partial beds of sand,

or mud, or lime, first in one place and then in another. The dry land which seems so solid and imperishable is slowly wasting away, every hill and mountain, every valley and every plain, losing some little particle from time to time. If any mass of land lose but one single grain per annum, and that loss be continued for as many years as its bulk contains grains, it must ultimately be altogether destroyed, and its materials strewed over the bed of the sea.

This process is no vain imagination of the brain, nor unnecessary supposition of that which only might take place ; it is a literal and certain truth, it is going on around us every day of our lives, and has been going on for a period of time vast beyond all human conception, unceasingly, uninterruptedly, day and night, summer and winter, over the whole surface of the earth.

Our dry lands are slipping and sliding from under our feet more slowly but as surely as the glacier slides beneath the feet of those who traverse it, and think it, perhaps, to be not only solid but immovable ice. The life of a man is as transient in the one case as the passage of the traveller in the other ; even the duration of nations of men and the existence of the whole human race covers but a small part of the time that has elapsed during some of even the most recent of the great changes that have taken place on the surface of the globe. The geologist is of all men the one who is likely to be most fully impressed with the graphic truth of the comparison which Homer puts into the mouth of Glaucus, in his singular colloquy with Diomede, between

the succession of the generations of men and the fall and renewal of the leaves of a forest :—

> *οἵη περ φύλλων γενεὴ, τοιήδε καὶ ἀνδρῶν*
> *φύλλα τὰ μέν τ' ἄνεμος χαμάδις χέει, ἄλλα δέ θ' ὕλη*
> *τηλεθόωσα φύει· ἔαρος δ' επιγίγνεται ὥρη·*
> *ὣς ἀνδρῶν γενεὴ, ἣ μὲν φύει, ἡ δ' ἀπολήγει.*
>
> ILIAD, vi. 146.

Like as the generation of leaves, so also of men ;
For of leaves the wind streweth some on the ground, but the forest
Putteth forth others in its growth ; and the season of spring cometh on ;
Thus the generation of men, the one groweth, the other cometh to an end.

To the mind's eye of a geologist, however, not only are the leaves fleeting, but the trees and even the forest itself ; for he looks back to the time when the very ground on which it stands did not exist, and forward to that when it shall be no more.

Before any firm step can be taken in the study of geology, this enlarged view of time must be clearly gained and fully comprehended as a reality. Without it we cannot understand even the plainest and simplest facts, not so much as the formation of the commonest stone about us, or of the sand and pebbles on which we daily walk. With it we can comprehend how the very slow and gradual action of such operations as have now been described can produce vast changes in the composition and in the structure and position of the component parts of the earth's crust.

Let us briefly sum up these operations : In Chapter

I. we saw reason to believe that the earth has a great internal temperature. In the four succeeding chapters we learnt something of the external manifestations of this internal heat. It appears that molten rock exists beneath the solid external crust, and that small portions of it are now and again ejected on to the surface in the form of lavas and ashes. These ejections, however great their mountainous piles may appear to us, are obviously but the little spittings and boilings over of the great furnace below.

We also learn that while large portions of the crust of the earth remain tranquil and motionless for long spaces of time, other parts are occasionally shaken by vibrations, and are permanently raised or lowered, either with earthquake shocks, or slowly and gradually, so that the movement is not apparent to our senses. These motions affect the whole thickness of the earth's crust to some great but entirely unknown depth, and are obviously those by which the ground that was the bottom of the sea has been raised into dry land, or the dry land depressed so as to become the bottom of the sea; and by which the originally horizontal beds composing the earth's crust have been tilted, and bent, and broken, in the fashion in which we find them in our hills and mountains, and even beneath so many of our plains.

In the two subsequent chapters we saw that on those parts of the earth's crust which become depressed beneath a certain level, and therefore overflowed by the sea, deposition of materials is always occurring, now in

one part and now in another, those materials ultimately forming solid rock. These materials are the result either of the mere mechanical transport of fragmentary solid matter, or of the re-solidification of matter that had been dissolved, the latter taking place chiefly through the instrumentality of the vital action of animals or plants.

The ocean, then, is the great producer of stratified rocks, and its bed the womb in which those rocks are generated; while rain, and frost, and wind, and the surface of the sea which the wind agitates, are the destructive powers under the influence of which all previously formed rock is liable to be ground down.

Here comes in a curious conclusion; supposing that at some long past period of the earth's history all those internal powers, of which earthquakes and volcanoes are external symptoms, had become quiescent and altogether ceased to act, many, if not all, of the dry lands of that period would before this have disappeared, and their materials been strewed beneath the sea. There might then have been no dry land left upon the globe if fresh areas of it had not been elevated. These great internal powers of disturbance then, which sometimes at the moment of their paroxysms produce such temporary ruin and destruction to man and his works, are in reality beneficial and conservative agents, and actually necessary to the life of the globe as a habitable world, in keeping up a proper balance of dry land upon its surface. Not only are the rocks, which have been elaborated beneath the sea-level, from time to time raised

above it, now in one part, and now in another, but their deeper parts are indurated and solidified, and often half crystallised by the heat proceeding from the interior, and they are moreover strengthened and supported by means of great masses or large bands of igneous rock thrust up and injected among them. Additions are even made to their surface also by the igneous materials ejected through them, either in a molten state as lava, or as fragmentary ashes.

There is then a constant action and reaction in the various physical agencies which are always at work on different parts of the earth's crust. Apparent destruction is constantly taking place in some parts, only to prepare the materials for re-construction in others. Powers which seem to cause nothing but ruin are in fact employed in repairing the ruin caused by agents that seem harmless. The precipices and peaks of the mountain crests, the ravines and abysses that yawn in their flanks, are not, as is often supposed, the result of the convulsive action of internal force, but of the slow and silent influence of the weather through uncounted time. The materials gained from this erosion and partial destruction of the mountains now form the most fertile plains, or will form them when the internal forces lift them from beneath the sea.

The heat and force which are occupied below in hardening and kneading together the materials of future mountain chains, and which ultimately raise them to within the region of atmospheric destruction, are in fact preparing them to resist that destruction as long as

possible, so that they may be able to stand for a time as mountains, in order to condense the atmospheric moisture, and send it down upon the plains in refreshing showers and fertilising streams. The internal movements, which have tilted, or bent, or broken the beds below the surface, have in that way brought them within the reach of man, and facilitated his extracting those which may be of use to him. These fractures also compel much of the atmospheric water which sinks at one part beneath the surface, to come back to it as springs in another. They form cavities also, which become the receptacles of useful minerals that require the more recondite chemistry of nature's laboratory to be put in action for their production. We may reasonably conclude then that the advantage of mankind was one of the ends contemplated by the great Author of Nature in the creation of all this wonderful and elaborate machinery, though geology combines with astronomy in rebuking the impertinent presumption which would make Man the be-all or the end-all of the creation of the universe, since all the operations and processes which are here alluded to have been in operation for a time compared to which that of the existence of man is but as a rain-drop to the ocean.

PART II.

Some of the Facts observable in the Crust of the Earth.

CHAPTER IX.

STRUCTURE OF ROCK BEDS.

I WILL now suppose that the preceding chapters have been read, and that the facts stated and conclusions drawn have been accepted as true.

Before we can proceed farther, however, with anything like satisfaction, I must ask you to do something else than read. You must go out and observe. Unless you do this, it is of no use to attempt to understand anything more of geology.

A blind man might just as well try to learn the art of painting as any one attempt to understand geology without personal observation of those objects on the structure of which the whole science depends.

If I were to ask if you ever saw a gravel pit, a sand pit, or a stone quarry, you would probably think it a very silly question. Yet the chances are a hundred to

one that you never did really see what is to be observed in them. If, therefore, there be any kind of opening into the earth, be it natural or artificial, pit, or cliff, or quarry, or cutting, within a walk of you, I must insist on your going, not merely to see that such a thing is there, but on your studying it attentively; and taking every opportunity of doing this, for every different kind of rock you can meet with. If you do not choose to do this you must take your geology on trust, and indeed had better shut up this book and not trouble yourself any further on the subject.

If, however, you will take the slight trouble of walking out and opening your eyes, and really seeing things instead of merely looking at them, and if you will then ask yourself the reason of what you see, and how it came to be as it is, you will find that cliffs and quarries may become as interesting and instructive as books; and I will endeavour in this chapter to help you to read them. When you have acquired that simple art, you will find yourself almost in the condition of a man in a foreign country, who, having been hitherto ignorant of the language, has eventually acquired it, and begins to understand what the people around him are talking about.

Lamination and Stratification.—Let us suppose then that we visit a quarry, or a cliff of sandstone, or limestone, or shale, or any variety of stratified rock, and that these beds are nearly or quite horizontal. The first and most obvious fact is, that there are beds which are naturally distinct from each other, and if a large face of

the rock be tumbled down, these beds readily separate from each other. What is the reason of this? Let us look a little more closely at them, and take, in the first instance, a single block of rock or part of one bed. In most cases this block will have a sort of "grain," parallel, or nearly so, to the upper and lower surfaces of the bed; and will break or split more readily in the direction of this "grain" than across it. On more closely observing the "grain," and employing a magnifying glass if necessary, we shall perceive that the "grain" consists of various layers, sometimes as thin as paper, differing from each other in texture or colour or composition. In all shales and in micaceous sandstones the cause of the grain or lamination of the rock is very obvious. It is plain that the bed was formed by the gradual accumulation of thin films of clay or of micaceous spangles settling down at the bottom of some water from time to time.

Had large quantities subsided at once, and very rapidly, the arrangement of the particles would have been confused, and the whole have formed but one inseparable layer. As in many cases 50 or 100 of these films or layers can be counted in the thickness of an inch, it follows that so many separate acts of deposition were required to make that thickness.

This is obviously a process requiring some time, so that a bed of a foot or more in thickness could not have been formed in less time than several years, to say the least of it.

Other beds which do not show this very fine lamina-

tion may have been more rapidly accumulated, and of some perhaps the whole materials were swept into the water by a single flood or other accident, and subsided at once to the bottom.

If, however, we are compelled to allow some considerable time for the formation of a single bed that is made up of many laminæ, each the result of a separate act of deposition, we must, by the same rule, allow a much longer period of time to be necessary for the accumulation of several successive beds lying one over the other, such as we can see in all quarries of stratified rock.

If their entire materials had been thrown down rapidly or at once they would not have had the arrangement of separate beds, but would all have made one confused mass. The very fact of the beds being separate proves that they were formed at separate times, and that the intervals between these times were long enough for a partial or complete consolidation to take place in one bed before the next was deposited upon it.

What the real length of these intervals was we cannot tell, but in some cases we have distinct proof that it was very long—long enough for some generations of animals to live and die in the water before the deposition of the next bed, or long enough to allow of several other beds being formed in another part of the water, which there intervene between the two.

In Fig. 7 these facts of lamination and stratification are represented in a rough diagrammatic fashion, for the purpose of making them distinct, the lined beds being

intended for shales, the dotted for sandstones, and the plain bed in the centre for a limestone more or less

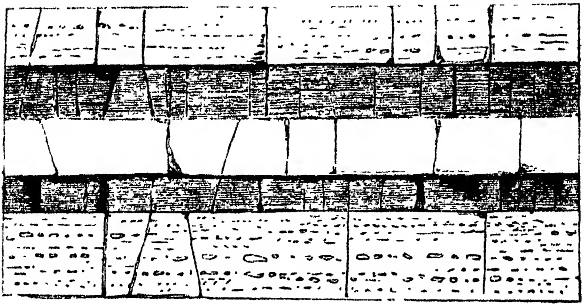


Fig. 7.
Lamination and Stratification.

entirely composed perhaps of layers of fossils, which, however, are not drawn.

In such a succession of beds, therefore, each one represents the conditions which prevailed over a certain area for a greater or less length of time; it consists of the particular sediment that was being continually deposited during that time, and encloses the remains of the animals then living in the water above; while the surface of each stratum must be looked upon as having formed the actual bottom of the lake or sea during the interval of time which elapsed before the deposition of the next successive bed.

Simple as are the facts now described, they are really the foundation on which the whole superstructure of geology rests. All that is required to be taken for granted is, that a series of beds, resting one on another,

was formed in succession, that the lowest is the oldest and the uppermost the newest, and that the relative place of the others proves their relative age.

Oblique Stratification, or False Bedding.—In the above description and figure, the shales and sandstones are represented as horizontal, one bed resting evenly on another. In some deposits, however, great irregularity is observable in the arrangement of the beds, different sets of layers inclining in different directions, and consisting of different coloured or different sized materials.

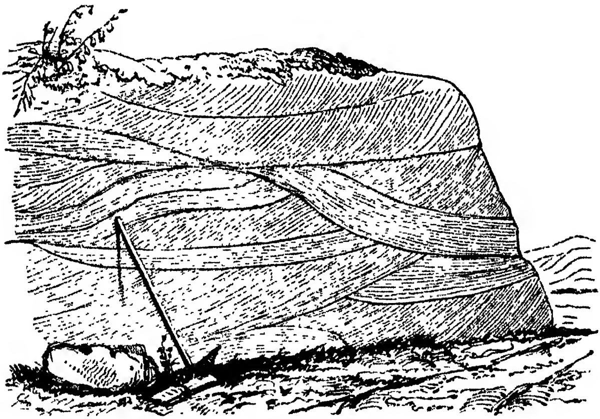


Fig. 8.

(See Fig. 8, which is taken from a sketch made on the coast of Waterford.)

This structure, sometimes called *False-bedding*, is a proof of frequent change in the direction and velocity of the currents which brought the sand and gravel

into the water. A current moving over an uneven surface, and drifting particles along the bottom, will arrange them in different positions; here piling them up against a bank, there depositing them on a slope. A subsequent change in the velocity or direction of the moving water may cut off and remove a portion of the bank, or excavate a channel through it; and this fresh surface or hollow may again be covered over or filled up with layers having a different direction from the first. Such appearances generally indicate shallow water, and are often seen in cutting through an old estuary or delta. Sometimes, however, the latter exhibits a more regular structure, which perhaps may be more truly called "*False-bedding*," since it is much more likely to be mistaken for true stratification. Where a river forms a delta in a lake or sea, the shore of which has a considerable inclination, though the upper layers (last deposited) may be horizontal, the lower layers are always more or less inclined according to the slope of the shore; and as deltas are sometimes of great size (see p. 102), a series of inclined beds may thus be produced of considerable extent and thickness. A good instance of this is figured and described in Lyell's *Student's Elements*, 1871, p. 20.

Inclined beds may also be extended so as to overlie a horizontal surface, and we then have the arrangement shown in Fig. 9, taken from the late author's Memoir of the South Staffordshire Coalfield. Here a set of sandstones, *a*, dip regularly down on to a bed of coal, *b*, and retain the same position over an area at least a

quarter of a mile square. From exposure of the sandstones alone, it was originally thought that the beds had been tilted into their present position, until the

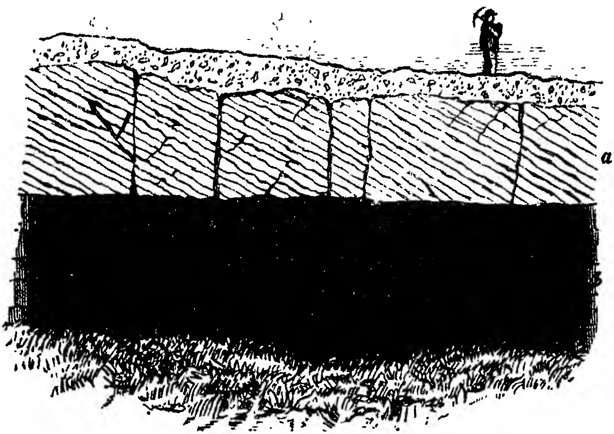


Fig. 9.
Inclined Sandstone on Horizontal Coal, near Wolverhampton.

above-figured quarry was found showing that the beds were so inclined during the process of formation.

Ripple or Current Mark.—Another effect of a current is to produce a "ripple" or "current mark" on the surface of a bed. This rippled surface is seen on the sands of the sea shore, when left dry by the tide, and also occasionally on the sandy bottom of a brook or any other running water. It is produced on the sea beach, not in consequence of the ripple of the wave impressing its form on the sand below, which would be an

impossibility, but from the drifting of sand by the current of water caused by the advancing or receding tide. Wind moving over the surface of water causes a ripple on that surface. Water moving over the surface of fine sand causes a similar ripple upon it.* If this rippled surface be covered by a film of clay, or acquire some degree of consolidation before another layer of sand be drifted over it, the form may be permanently fixed. Fossil current marks are, indeed, often found in sandstones and sandy shales of all ages, telling of similar conditions and similar agencies to those which we see at present around us.

Joints.—In Fig. 7, besides the horizontal lines representing the lamination and stratification, there are some vertical and oblique lines cutting across the beds. These represent the "joints," which may be observed in every exposure of solid rock of any kind whatever.

They are those natural planes of division resulting from the contraction which is a necessary consequence of solidification. Joints or natural cracks of some form or other invariably occur in dried mud or clay, in starch, and in the slags of an iron or glass furnace; and they may be observed in the newly formed coral rock on the surface of a coral reef, in lava streams only just cooled, as well as in all other rocks.

* This may easily be seen by placing some fine silt in a basin half full of water, and swaying it gently to and fro. Distinct current marks will be produced on the silt at the bottom.

They are generally numerous in proportion to the amount of induration which a rock has undergone, and vary slightly in form and character according to the structure and texture of its materials.

In bedded or stratified rocks there are commonly two principal sets of joints nearly at right angles to each other, and also at right angles to the stratification, besides others more irregular and running in various directions.

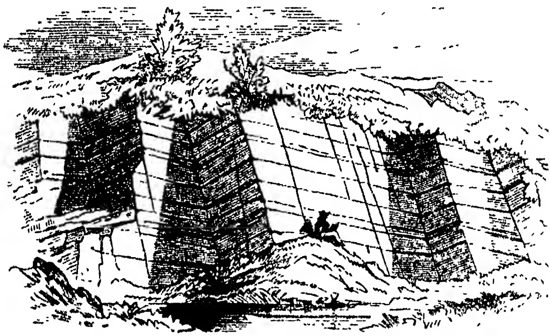


Fig. 10.
Joints in Limestone. Quarry near Mallow, County Cork.

Fig. 10 is taken from a sketch of a limestone quarry near Mallow, County Cork, drawn by Mr. Du Noyer, but almost any other quarry would have done as well. The regular lines which slope gently from the spectator towards the left represent the planes of bedding or stratification, the vertical lines across these are joints. The faces of rocks, one set of which receive the light, while the other set are in shadow, are the surfaces

100 or 200, and in diameter from 1 or 2 inches to 6 or 8 feet.

The Giant's Causeway, and Fingal's Cave in the Island of Staffa, are well-known examples of this prismatic jointing. In those instances it happens to be exceedingly regular, but ruder examples of it may be seen in almost every quarry of basalt, in many exposures of felstone, and in the central parts of old lava streams in all parts of the world. A similar structure is also assumed by some other substances, such as starch, when passing from a fluid to a solid state.

The joint planes that form the columns appear always to have commenced near the surfaces where the cooling and consolidation began, and to have struck thence towards the interior; but the occasional transverse articulation of the columns, by which they are divided into short pieces with a rude kind of ball-and-socket joint, is probably the result of a tendency to cool from separate centres within the mass, which increase as spheres until their mutual interference forces them to take a hexagonal outline, their superposition being perhaps determined by the prismatic master-joints.

Fig. 12 is a sketch taken from a photograph of a quarry in basalt, at a place called Pouk Hill, Staffordshire. This basalt here forms a small mound, the columns in the upper part of which are nearly horizontal, but show a tendency to radiate in all directions from the centre, or rather to strike inwards from every part of the original surface of the mound. Below they are vertical, rising directly from the floor of Coal-

measure clay beneath; the tops of these vertical columns, however, are also inflected towards the central

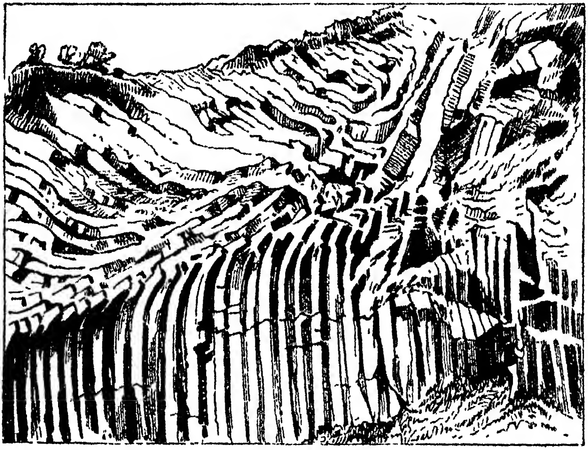


Fig. 12.
Pouk Hill Quarry, near Walsal, Staffordshire.

portion of the mass, and the whole arrangement is that which would be produced by the striking inwards of joint planes from the external surfaces originally bounding the cooling mass.

CHAPTER X.

INCLINED BEDS.

In the imaginary quarry which we just now visited, the beds were supposed to be horizontal. They are, however, in reality, quite as often inclined to the horizon at various angles. Each bed passes down into the earth under the one above it, and that goes down beneath the next, and so on. If we were to select any valuable bed, and follow it by digging or mining, we should, in many cases, still find it going down deeper and deeper, until it acquired a depth at which it would become unprofitable to work it, and we should be obliged accordingly to leave it still going down into the earth.

Dip and Strike—This downward inclination is called the *dip* of the bed. The opposite to the dip is the *rise*, and we may, in some districts, where beds are exposed by a cross cutting, find a succession of beds rising up one after another, quite regularly for a great distance.

In these cases it is clear that the last bed which rises up must come from under the entire thickness of beds above it, and must lie at a correspondingly great depth at the other end of the cutting.

The appearance of an inclined bed at the surface is

called its *outcrop* or *basset.* The line at right angles to the plane of the dip,—that is the line of outcrop along a level surface,—is called the *strike* of a bed. The strike is always in the plane of the horizon,* while the outcrop depends on the surface of the ground; hence the true strike of a bed will coincide with its outcrop only when the surface is horizontal.† Sir Charles Lyell compares dip and strike to a row of houses running east and west, "the long ridge of the roof representing the strike of the stratum of slates, which dip on one side to the north, and on the other to the south." Any exposure of the outcrop of a series of beds, whether it be in an artificial cutting or in a natural cliff, is called by geologists a *section.* These sections are what a geologist first seeks for and studies when he wishes to learn the subterranean structure of a district.

Geological Map and Section.—As it is essential to understand how this investigation is carried on, it will be advisable to explain it a little more fully.

Having procured a good map of the district we are going to examine, a pocket compass, and a small instrument called a clinometer, by which we can determine the angle at which a bed inclines from the horizontal plane, we begin to look for exposures of rock. The district may perhaps at first appear to be entirely

* It is in fact the intersection of the plane of the horizon with the plane of the dipping stratum.

† The use of strike is to show where the beds are tending, and where we may expect to find them again; and so the term is sometimes applied loosely to the line of outcrop, when that is a pretty straight line.

covered by soil and vegetation, but when thoroughly examined it may show here and there some crags of bare rock, some bare cliffs on the side of a river, some cutting on a road-side, or some quarries. Let Fig. 13 be a piece of our map traversed by a brook and a road, and suppose that we find four quarries of limestone in the north-east corner of the district, all the beds of which dip to the south-west at an angle of 20°. Let us represent these limestones by the cross-barred lines

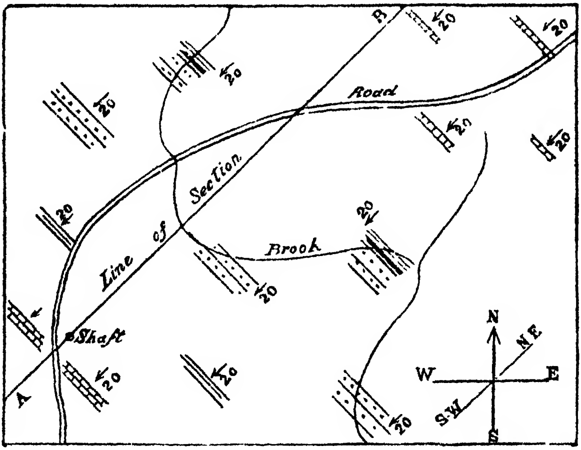


Fig. 13.
Geological Map.

in the north-east corner of the figure, drawing them in a north-west and south-east direction to represent their strike, and indicating their dip by an arrow with 20° annexed to it.

In examining the banks of the brook, suppose we

find, in two places lying in the same line of strike, some shales represented by plain close lines, a bed of coal represented by the thick dark line, and some sandstones represented by dots, and, for simplicity's sake, let us suppose them all to dip south-west at 20°. Then suppose that we find one or two other detached exposures of sandstone and shale to the south-west of the above with similar strikes and dips. And lastly, suppose that in the south-west corner of the district we find some more limestone of quite a different kind from that in the north-east corner, but still dipping to the south-west at 20°.

It will be obvious at once that these limestones in the south-west corner of the map lie above all the other rocks, while the limestones in the north-east corner rise out from underneath all the rest.

But in such a case as that supposed, where the exposures of rock are sufficiently numerous, we learn not only this general fact, but we have data for calculating the total thickness of the succession of beds which strike through the ground, and at what depth any one of them will be found if we desire to sink to it.

The easiest way of making this calculation is by drawing a section, at right angles to the strike of the rocks, through any points we may select. Suppose that we wish to sink a pit, at the part marked "shaft" in the map, in search of the coal, and that before commencing we wish to know how deep the coal is there, and how far it is to the limestone below it. We take the map and draw the line A B from south-west to

north-east through the spot we select for our shaft, and then with some levelling instrument ascertain the undulations of the ground along that line, taking the "level of the sea" as our "datum line." Having thus got the true outline of the ground, which we may suppose to be given in Fig. 14, we draw lines inclined at an angle of 20° towards the south-west at the several spots where the section line is cut by the outcrops of the beds, or by straight lines joining them, and this section will then show us the depth at which the shaft will reach any of the beds. Similarly, if we wish to

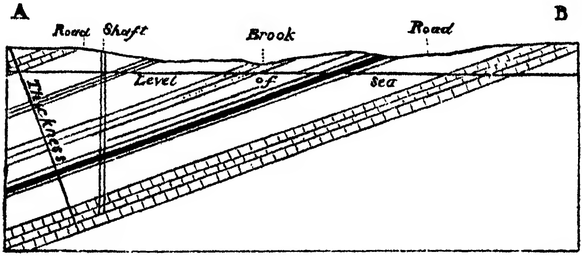


Fig. 14.
Geological Section.

know the thickness of the whole succession of beds from the highest to the lowest of those exposed in the district, the length of the line marked "thickness" in Fig. 14, drawn at right angles to the beds, will give it us, when measured on the scale we adopt for our map and section.

Now these are all exceedingly simple operations, but they give us results of very great interest and importance. Not only do they show us how much we

may learn as to the subterranean structure of the ground beneath the surface at any particular place, but they explain to us how it is that, by continuing these observations and measurements at different places, we may extend this knowledge to depths far beyond the reach of any actual mining excavation. We may thus learn, by inference, the structure of the whole crust of the earth, though we can never hope to penetrate by actual exploration to more than a very trifling depth into it.

It is true that as all beds are merely partial deposits, and end more or less rapidly in all directions, and as moreover many beds vary in thickness in different directions, we might be thrown out in our calculations as to the occurrence of any particular bed, or as to its exact place beneath any spot; but since these changes only take place in a certain way, and with limitations which a little experience enables us to calculate on and allow for, we may, without any important error, follow out the several groups of beds, however much particular ones may have altered their character or been replaced by others in the space of ground we had passed over.

It is indeed often wonderful how persistent a thin bed is, and how permanent are the characters of a small group of beds over areas of many square miles, or sometimes even many hundreds of square miles. At other times, it is true, their changes in thickness or character are rapid and frequent, leading hasty observers perhaps very far astray, but only requiring care and perseverance to understand and explain.

Inclination of Beds.—The angles of inclination at which beds of stratified rock may be observed to rest at different places, vary indefinitely from the horizontal to the vertical.

It is quite possible that some beds may have been originally deposited on a slope; banks of sand and gravel, for instance, may be formed under water with sloping sides like those we see naturally or artificially formed on dry land. These, however, cannot be very extensive beds, for if a bed only occupy the space of a single square mile we can hardly conceive it possible that it could all have been deposited in a sloping position; since if it had, the bottom of the water must have deepened for a whole mile, and one part of it been so much deeper than the other that it would be very unlikely to have had a regular and similar deposit thrown down on it. Beds inclined from original deposition may therefore be distinguished from those subsequently tilted, by their never extending to any great depth, by their often ending abruptly against horizontal beds, as in Fig. 9, and generally by being irregular and rapidly thinning out in various directions.

Moreover, the inclination of such beds is seldom, if ever, more than 45°. It is impossible even for man to make a bank of loose earth more steep-sided than a railway embankment, because the materials roll down if there is a steeper slope than one of about 35°; shingle and gravel sometimes make a slope of 45°, but sand rarely more than 35°; in water the angle is much the same, notwithstanding the diminished specific

gravity, unless the particles are very small and round, so as to be lubricated by the water; from 25° to 35° are frequent inclinations.

When, therefore, we find a series of continuous beds tilted up at an angle of more than 45°, and still more when they are nearly or quite vertical, we may feel absolutely certain that they have been lifted up by the internal movements of the earth, and lifted more in one direction than in another, so as to have been set

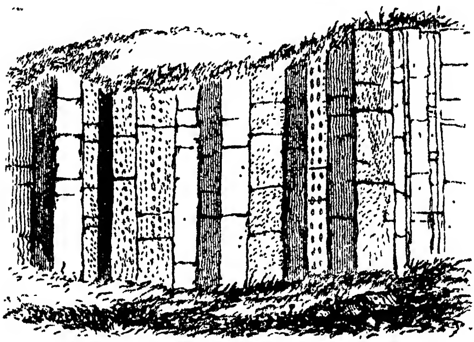


Fig. 15.
Vertical beds once horizontal.

on end. Suppose, for instance, we found a series of beds like those in Fig. 15, some of which contained rows of rounded pebbles in regular layers, embedded in sand. It is obviously quite impossible that they could have been deposited in the position we now find them, since no natural action could plaster loose materials against an upright wall. The beds must have been deposited in a horizontal position at the bottom of the water, and

have been subsequently pushed up on one side or let down on the other, or otherwise tilted by both actions.

There is also another very obvious deduction to be drawn from the inspection of this section and the one given in Fig. 14, p. 148. The beds terminate abruptly at the present surface of the ground. But they could not have terminated in this way when they were originally deposited, as may be seen at once by simply holding the book so that the beds in Figs. 14 and 15 are horizontal, when it will be obvious that strata formed by the gradual deposition of earthy sediment in water could not end with such an outline as their present surface has.

When, then, we find a series of beds many hundred feet thick, all rising up at a steep angle and terminating abruptly at the surface of the ground, we may be sure that that is not their original termination, but that a part of them has been cut off and removed by some means so as to produce the present surface. We shall have to recur to this subject in a future chapter.

CHAPTER XI.

BENT AND BROKEN BEDS.

In the previous chapter we saw that strata were often inclined to the horizon at various angles, lying, in fact, in all positions from the horizontal to the vertical. But they are also often curved, so as to dip at different angles and in different directions.

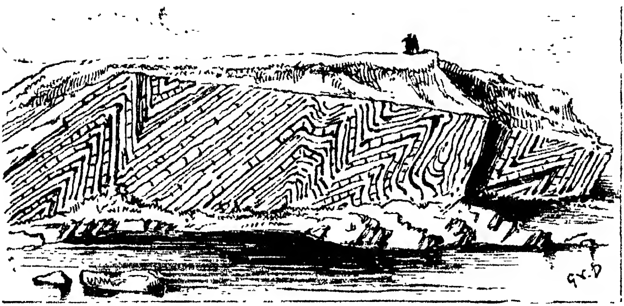


Fig. 16.
Contortions at Lough Shinny, County Dublin.

Contortions.—Where these curves are compara-

tively small, so that several of them are visible at once, they are called "contortions."

Fig. 16 is from a sketch by Mr. Du Noyer of some cliffs at a place called Lough Shinny, on the coast of Dublin, and represents some contorted beds of dark limestone, with thin black shale layers between them. It will be seen that the beds are crumpled and bent at every angle, both to the right and left of the spectator. But a visit to the shore at low water shows them to be curved fore and aft as well as sideways, in a way that could not be represented in any one sketch. Long oval domes rise up here, and long oval or variously shaped basins appear there. In some places they look like nests of boats, one inside another, standing upright, and cut down to one level; or else like boats bottom upwards, and the sides of the outer ones cut off, so as to let the inner ones appear through them. In some places the beds of hard limestone are wrinkled up like a crumpled piece of stiff paper that has been squeezed in the hand. The beds could not have been soft when they were so squeezed, or they would have been all kneaded together into one undistinguishable mass. The softer beds of shale between the hard limestones are often thus squeezed and accumulated in pockets of the other rock. The contortion was in fact produced by the slow and gradual action of a great force, when the beds, already consolidated, were deep down in the earth, and the superincumbent pressure of the beds above them prevented them from breaking open as they

would have done if the same force had been applied to them at the surface.

Similarly contorted beds may be seen in many parts of England and Wales, and Scotland, as well as in other parts of Ireland, and in many other countries; and the same conclusions may be always drawn respecting them.

Anticlinal and Synclinal Curves.—When these curves are on a larger scale they are called "*anticlinal*"

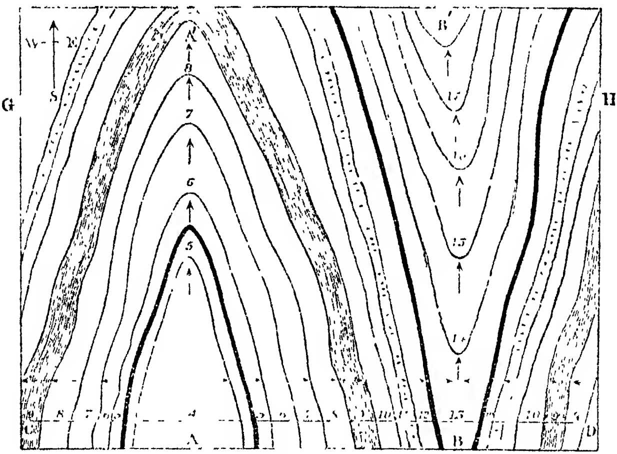


Fig. 17.
Ideal plan of the outcrop of curved beds.

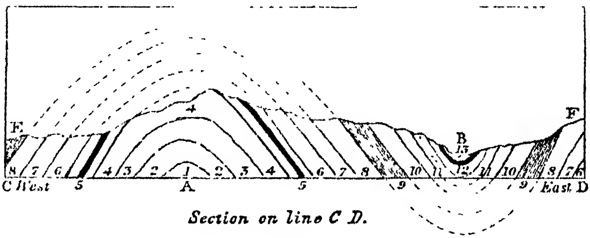
and "*synclinal*" curves. The anticlinal curve being "that of which the sides incline *upwards towards* each other like the roof of a house, while the sides of a synclinal curve incline *downwards towards* each other, like those of a trough."

Curved beds may be supposed to be bent over an imaginary line, which may be called the axis of the curve, and this axis may itself be either horizontal or inclined.

When the axes are inclined, a map or plan of the undulating beds will be something like that shown in Fig. 17.

Suppose that, in this plan, A represents the top of the bed No. 4, bent up into an anticlinal ridge, and dipping east and west, as shown by the two side arrows on it, and that on the top of the ridge it also dips gently towards the north, as shown by the third arrow. Where the bed No. 4 sinks into the ground in that direction, the bed above it will of course meet over it, and will itself gradually sink into the ground towards the north as well as towards the east and west, and thus we shall get the beds 5, 6, 7, and 8, gradually coming in and curving over the top of the ridge.

If we draw a section along the line CD across the



Section on line C D.

Fig. 18.

curved beds, they will appear, as shown in Fig. 18, dipping on each side of A, and forming the anticlinal

curve there. If we now suppose that, after dipping for a certain distance towards the east till the bed No. 4 is covered successively by those numbered up to 13, these beds curve up again, they will form the synclinal curve B, and the beds will rise towards the east and crop out again at the surface in that direction. But suppose that the imaginary line or axis about which this synclinal curve takes place is itself also inclined towards the north, like that of the anticlinal, then the plan, Fig. 17, will show still higher beds coming into the hollow of the curve as we walk along it towards the north, and we shall get the beds numbered 14, 15, 16, 17, taking the ground in that direction.

If then we were to draw another section across the curves farther north, between G and H for instance, it

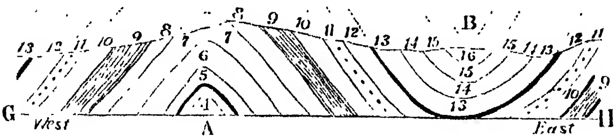


Fig. 19.
Section between G and H.

would be like that given in Fig. 19, in which the bed No. 4, that formed the surface of the anticlinal ridge in the southern section, Fig. 18, is now deep beneath the surface, which is here formed by bed No. 7. Similarly the bed No. 13, which was at the surface in the

centre of the synclinal curve in the first section, is here deep below the surface, which is now formed by bed No. 16.

This imaginary plan and its accompanying sections, although imaginary, were suggested by the actual survey of numerous examples. Abundant instances of similar curves may indeed be seen in the maps of the Geological Survey of the British Islands, as well as in those of the government surveys of other countries, and they are familiar to all geologists who have examined districts in which the rocks have suffered much disturbance.

These flexures of the solid rocks take place on every conceivable scale of magnitude. The map and sections given above might either represent a district of a few yards in extent, and the numbered parts single beds of two or three feet in thickness; or they might represent great groups of beds hundreds of feet thick, and the map be supposed to be one of a great country.

Faults.—If hard and solid rocks can be bent into curves through a thickness of many hundred or several thousand feet, we shall have no difficulty in understanding that they might be broken through if the same force were differently applied, and also that the separated portions might be raised or depressed far above or below those with which they were originally connected.

These fractures and displacements of large bulks of rock are called by geologists "dislocations" or "faults." The latter is a term introduced by coal-miners, though

they misapply it in some districts by including other kinds of irregularities in beds which have no connection with fracture or dislocation.

Fig. 20 is a section across a fault, A B being supposed to be the surface of the ground, and *a b* a slanting fault breaking through the broad black band, which may be supposed to be a bed of coal. The two sides of the fault are spoken of as the "upcast" and "downcast" sides, and the amount of the dislocation measured vertically is commonly called the "throw" of the fault.

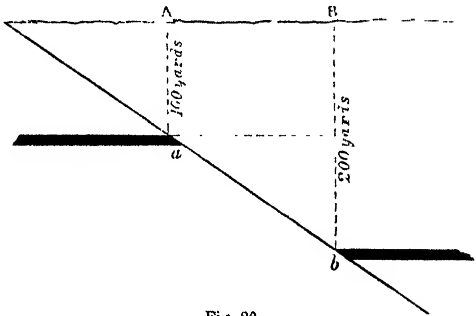


Fig. 20.
Section of a Fault.

If in Fig. 20 the depth of the upcast piece, where it is cut by the fault, be only 100 yards, while the depth to the downcast be 200 yards, the fault is said to have a "downthrow" or an "upthrow" of 100 yards. The terms "up" or "down" are used indifferently, according to the side from which we view the fault, since it is generally impossible to say whether one piece has been

upraised or the other depressed, or whether both movements may not have combined to produce the result.

The amount of the dislocation varies from a mere "hitch" or "heave" of a few inches or a few feet, to a great throw of several hundred or even one or two thousand feet. Dislocations to that amount have been actually proved in coal-mining, and they can be calculated with very considerable accuracy, without mining, where the outcrop of the broken beds can be seen near the fault which cuts them, and the angle of their dip ascertained.

There are many "faults" which have been traced and laid down on the maps of the Geological Survey, both in North Wales and Ireland, by examining these broken outcrops, and some of them must have "throws" of at least 3000 feet, and probably more.

Faults are sometimes vertical, but more commonly inclined at various angles, and the inclination is called their *hade* or *underlie*; thus we speak of the *dip* of a bed, and the *hade* of a fault. There is also a relation between the inclination of a fault and the direction of its throw—viz. that it generally hades under the downcast side; exceptions to this rule are called *reversed* faults, as shown in Fig. 21, but they are not of common occurrence.

Figs. 20 and 21 exhibit simple lines of faulting, but there are other more complicated forms produced by the various ways in which rocks yield to pressure from beneath; perhaps the most noticeable of these are "*Step*" and "*Trough*" Faults. In the former (Fig. 22)

a series of parallel fissures has broken the rocks into a number of steps, and caused the same bed to be

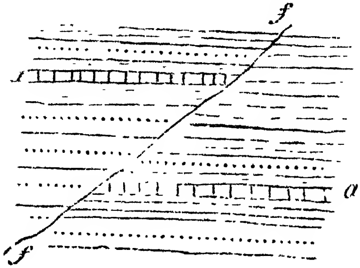


Fig. 21.
Reversed Fault.

repeated at various levels, thus possibly misleading the observer as to the number of the beds. Trough Faults, where wedge-shaped masses of rock are let down below

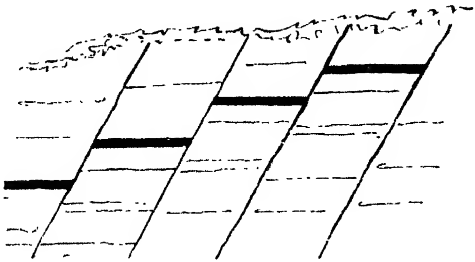


Fig 22.
Step Faults.

their former level, are still more complicated, but may be found described and illustrated in Chapter IX. of the author's larger *Manual of Geology*, third edition.

CHAPTER XII.

DENUDATION, UNCONFORMABILITY.

Denudation.—At the close of Chapter X. attention was called to the fact of beds ending abruptly at the present surface of the ground, and the inference was drawn that this surface was one that had been formed by the removal of much rock which had at one time existed above the present surface. If now you will turn to Figs. 16 to 22 you will see still more convincing proof of the truth of that inference.

Fig. 16 is taken from a careful sketch of an actual cliff. It will be seen that the contorted beds are all cut off at top by a nearly straight line, above which is an upper bank on which the figures stand, and that consists of loose gravel, clay, and sand. Examination of the sketch will show that the beds which rise in the centre of the crumpled anticlinal are the lowest beds shown in it, and that the beds in the sharp *vandyke* at the left of the sketch must be the same as those in the similar *vandyke* on the right of it.

Those beds must have been originally continuous over the central arch, and the level surface could only have been formed by the cutting away and removal of those parts that formerly connected the beds at the two ends of the sketch.

If we examine the map in Fig. 17, and the two sections across it in Figs. 18 and 19, we cannot resist the conclusion that, as those beds were, like all other beds, originally horizontal and continuous, they must not only have been bent by forces of disturbance proceeding from the interior of the earth, but large parts of them, as suggested by the dotted lines in Figs. 18 and 19, must have been removed and carried off in order to arrive at the present surface of the ground.

Figs. 20, 21, and 22 are equally illustrative of the same thing, the surface being horizontal, while great changes in level have taken place in the beds below the surface on opposite sides of the faults. Multitudes of instances are met with in coal-mining, where faults, of such magnitude as to bring in beds many hundreds of feet thick on one side of the fault, which do not exist on the other, nevertheless run for miles beneath a level surface of ground. The inequality which exists below has been entirely obliterated above, by the equal wearing down and removal of all the rocks, so as to produce the present uniform surface. Even when there is an external feature which coincides with the subterranean structure in direction, it rarely, if ever, equals it in amount. It is sometimes even exactly opposite to it, the surface of the ground rising on that side of the fault where the beds below it are thrown down. This opposition between the external feature and the internal structure is still more frequently observable in bent beds, as in Fig. 23 for instance, where the surface of the ground at A and B rises exactly

where the beds below dip, while it falls on either side towards the centre of the figure where the lowest beds rise up towards it.

Now the internal forces of disturbance, however they may bend or break the beds which compose the crust of the earth, cannot possibly remove and carry away any of the rocks at the surface. The only natural forces able to do that are those of moving water which act directly upon that surface. This action is called "Denudation," or the laying bare of rocks previously covered. The mode of action has been already described in Chapter VII., which treated it, however, not so much as the producer of forms on previously existing rocks, as the gatherer of materials for the composition of new beds. It was there shown to be caused by either the atmospheric agencies wasting the dry land, or the erosion of the sea along the margin of land. It can only take place then on rock which is near or above the level of the sea, and thus in itself proves the existence of dry land. All surfaces of denudation must, at one time, either have been land surfaces, or must have had land surfaces directly above them, which have been removed during the process of depression and denudation.

"Denudation," either marine or atmospheric, is the agent which, with a few exceptions, has produced all the existing external features of the land, the forms of the mountains, hills, glens, valleys, and plains (see p. 97 *et seq.*) The rocks of which the crust of the globe is composed have first been formed by

aqueous deposition or igneous injection or ejection; they have since been variously hardened by pressure, or cementation, or heat, or all combined, and in many places have been bent and broken, tilted or dislocated, and thus kneaded as it were into a complex mass of very various kind, the different parts differing both in position and composition. This complex mass has subsequently been worn and carved into shape by the erosive action of water brought to bear upon it, now in one place, now in another, the sea cutting into one part like a horizontal saw, rivers, cataracts, and glaciers, grooving it in others like gouges or graving tools.

Even widely-spread plains are often the evidence merely of the march of the sea across them, and the removal by it of the mountains that once covered them; the highly inclined and contorted bases of the mountains still existing beneath the plains like the foundations of old ruined cities and castles that had been long ago razed and levelled with the ground.

The only exceptions to the rule, that the form of the ground is due to the denudation, are to be found in those very recent deposits which we see in alluvial flats and deltas, in hills of blown sand, and in the cones of active volcanoes on which the rain has not yet begun to produce any appreciable effect.

Hills and Valleys.—Fig. 23 represents a frequent occurrence in Ireland, where the low ground is often composed of limestone, while the hills are made of peculiar black shales resting on the limestone, especially in those parts where the top beds of the limestone dip into

a basin-shaped curve, so that the internal basin has an external hill over it.

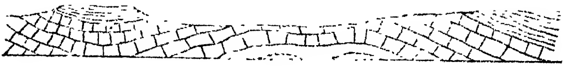


Fig. 23.
Synclinal axes forming hills.

This form of hill is very general; the reason being that the sloping strata of an anticlinal ridge are much more liable to be broken up and washed down the incline than are the beds of a synclinal fold, which merely present their edges to denudation, even though they are of softer material. Such hills, therefore, owe their existence in a great measure to the very position and circumstances which at first sight would lead one to expect a valley.

Volcanic mountains are *mountains of accumulation*. All other hills and mountains are either *those of cir-*

cumdenudation, which have been left comparatively high because of the wearing down and removal of the rocks that once surrounded them; or *mountains of upheaval*, the aqueous and igneous rocks of which are exposed by denudation, but are still at a high level,

because they have been thrust upwards from below by internal force.

Fig. 24 will serve to illustrate what is meant by hills of circumdenudation, in which the beds that form the bases of the hills are continued beneath the adjacent low ground, while those that form the summits are not found there.

Fig. 25 will in like manner show what is meant by hills of upheaval, the summits of which are formed of beds that rise up from beneath the adjacent low grounds, while these low grounds are formed of higher beds, that once spread continuously in horizontal sheets across the area in which the mountains now rise, but were worn away and removed during the process of elevation, or subsequently to it.

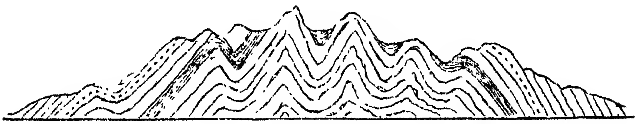


Fig. 25.
Hills of Upheaval.

Most of the mountain chains of the world are of this latter form, and they all owe their general external outline and the shape of their crests and summits to the influence of the action of the sea as they rose through its level; while their internal valleys, and ravines, and glens, are the result of atmospheric action on them since they became dry land.

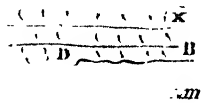
Unconformability.—Not only are the surfaces of our present dry lands all formed by this process of

denudation, but many surfaces which formerly existed as dry land, and are now beneath the sea. Some of these old land surfaces that have thus sunk beneath the sea are now being covered by fresh deposits thrown down on them. They must ultimately be deeply buried by the beds of rock now forming at the sea bottom, and those which will successively be formed there. But this action of the depression of old land and the deposition of new materials upon it, is not now taking place for the first time in the history of the globe; on the contrary, we have in the earth's crust many such old surfaces. There is perhaps not a single great group of stratified rocks entering into the composition of the crust of the earth that cannot be shown to

Fig. 26.
Simple Unconformability.

rest somewhere on an old surface of denudation, and to have in some part or other a denuded surface of its own on which some newer formation reposes. Wherever one formation rests upon the old denuded surface of another, it is said to be "unconformable" to it. This unconformability is sometimes obvious throughout, as it would be in Fig. 26, where the lower group of rocks *m m* have been tilted as well as denuded, and the horizontal surface A B produced, on which the

horizontal beds X X X have been deposited. In other cases, as in Fig. 27, the new surface may have been formed without any tilting of the beds, and both the



old set *m m*, and the new X X, may remain horizontal, or be equally inclined in the same direction. In this case, the unconformability may not be obvious at A or B, although it will at C or D, where the old surface cuts abruptly across the lower beds.

Contemporaneous Erosion.—There are certain phenomena which might be mistaken for each of the above-mentioned cases of unconformability. These are :—

1. That kind of "false bedding" noticed and figured on p. 135, where a considerable series of inclined beds ends evenly against horizontal strata, whether above or below. Such appearances may easily be mistaken for the simple unconformability in Fig. 26, particularly if attention is not paid to the differences between originally and subsequently inclined beds mentioned on p. 150.

2. From a slight change of level, or other cause, currents of water may erode channels or hollows in previously formed banks of sand or mud, and these

may be filled up by a part of the bed next deposited. This contemporaneous erosion and filling up might present an appearance in section very similar to that in Fig. 27, where both series of beds are horizontal.

Thus a section exhibiting evidences of unconformability only proves erosion to have taken place, and does not necessarily involve elevation and denudation, or denote a great lapse of time between the deposition of the two beds. Still the exceptions mentioned above only occur rarely and on a small scale; and where the rocks are unconformable over a large area, especially if the eroded strata seem to have been consolidated or metamorphosed before the deposition of the upper series, denudation and lapse of time may safely be inferred.

Overlap.—There is yet another kind of unconformability, to which the name of Overlap is applied. This consists in the greater extension of an upper series of beds beyond the limits of those on which they rest, so that they overlap and conceal their edges. This is shown on a small scale in Fig. 27; and Fig. 28 represents an old land buried under continually overlapping strata, which are conformable to one another, but unconformable as a series to the rocks below. Overlap, however, does not necessarily involve so much denudation as shown in the figure, merely proving depression to have taken place, which may have been so gradual as hardly to be noticeable in a single section, and only appreciable when the beds are traced over a considerable area.

We have, then—1. *Contemporaneous erosion,* denot-

ing slight change of level or alteration of currents, and taking little time to produce ; 2. *Overlap*, indicating depression continued for some length of time ; 3. *Unconformity*, indicating three processes—elevation into dry land, denudation, and subsequent depression ; the whole taking a long time to bring about. Since, however, all three phenomena are produced by the same set of agencies, there is likely to be every gradation between them. It is probable, also, that every unconformity is or has been connected with an overlap. This subject, however, awaits further investigation.

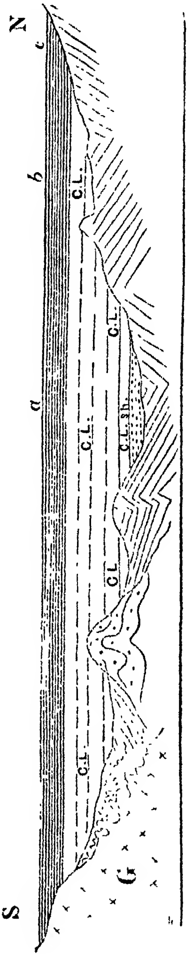


Fig. 28.

Diagrammatic section across County Dublin, showing Overlapping Bed-

* This figure is taken from p. 304 of Jukes' *Manual of Geology*, second edition, where a full and instructive explanation of it may be found.

CHAPTER XIII.

METAMORPHISM.

SECTION I.—METAMORPHIC ROCKS.

At the close of Chapter VII. the different varieties of clay are enumerated, one of them being Clay-slate. It is stated there that Shale is a clayey deposit, which splits into thin plates in consequence of its deposition as thin separate layers, but that Clay-slate splits into plates which are formed in another way. The plates of Shale are generally soft or brittle, while those of Clay-slate are more firm, and sometimes very hard and tough, so as not only to make much larger and thinner plates, but plates that will resist a much greater force than Shale will. Clay-slate is familiar to us all in "roofing slates" and "ciphering slates." Its hard, smooth, and even, but not polished surface, and its fine grain, are as conspicuous as the size and thinness of its plates, and it is obviously different from most other stones. The history of its production is a very remarkable one, for it belongs to a class of rocks which are called "*Metamorphic*" or "*Altered*" Rocks, since they have undergone alteration in structure and composition subsequently to their original deposition.

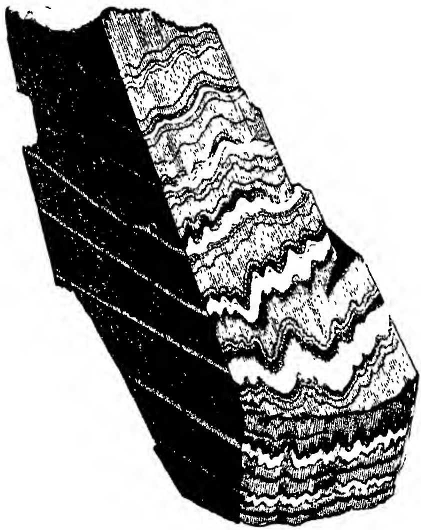
Cleavage.—Any one visiting a slate quarry must be struck by the fact, that all the rock will split readily in one given direction only, producing surfaces which run parallel to each other all over the quarry.

This tendency to split in one direction is called "cleavage." There are other planes of division which separate the rock into great blocks, but these are obviously the planes of stratification and the joint planes. In many slate quarries it is difficult to distinguish the joints from the planes of stratification, but in others it may be done by observing the marks of the lamination of the rock. The slates show little parallel bands varying in colour and texture, like those described at p. 132, and obviously formed by successive deposits of slightly differing layers of mud, or silt, or sand. These bands —the "stripe" of the slate, as Professor Sedgwick calls them—mark the original horizontal deposition, and the planes of division which are parallel to them are the planes of stratification. In some slate quarries, indeed, beds of Clay-slate alternate frequently with beds of limestone or of sandstone and conglomerate, so that the stratification there is left in no manner of doubt.

The "stripe" is rarely well seen in good slate, because the variations in texture, which make the stripe, prevent the slate from being good. The best slates are those in which the original grain of the rock was like that of a thick mass of very fine clay, perfectly even throughout. In such a mass the lamination and stratification are often imperceptible, even when it is first formed, and it will therefore be still more diffi-

cult to find them out when it has become converted into slate. Coarse inferior slate displays its origin better than the finer kinds; and the coarser the rock the wider apart do the cleavage planes become.

Fig. 29 is a portrait of a block of slate that would be worthless as a roofing or writing slate, but shows the original lamination and the slaty cleavage very



Block of Clay Slate.

well. The block is about a foot and a half high, and came from some small quarries in the neighbourhood of the Devil's Glen in County Wicklow. The white puckered bands which cross the block are pale green

layers of a very fine sandstone or gritstone, the rest of the block being purple clay-slate. The fine striæ drawn on the front of the block represent the cleavage planes, which do not traverse the pale bands. The lines on the left side of the block are only the artist's lines, which represent shadow and not the structure of the rock. The jagged edges at the top of the front show the tendency of the rock to split along the cleavage, and how difficult it is to split any of the cleaved part across, in the direction of the bedding, so as to leave an even fracture, although, before the cleavage structure was impressed on it, the rock must have had a tendency to split more readily in that direction than any other.

We can learn thus far from the examination of a mere specimen, but if we go out into "the field" and observe this cleavage structure over large areas, we find something still more wonderful about it. We may first notice the peculiarity that, no matter how the original beds may lie, whether inclined or thrown into curves, the planes of cleavage cut straight through them and across them in one direction only. This cleavage, then, must be a superinduced structure impressed upon all the rocks simultaneously after their formation, and either during the process of disturbance or subsequently to it.

Spaces many miles across, even whole mountain ranges, have had a cleavage structure communicated to them, running in one given direction by compass, throughout their whole extent. It is however observable that the direction or strike of the cleavage coincides

with the general direction or strike of the beds of the mountain chain when viewed on the large scale.

North Wales gives us a good example of this. The mountains of Caernarvonshire strike north-east and south-west throughout, and the cleavage always strikes north-east and south-west also.

In the Berwyn Mountains, however, while the strike of the beds in their southern part is north-east and south-west, the beds and the hills curve round as we approach Corwen, and run nearly due east thence to the borders of Shropshire. The cleavage follows this change of strike with great regularity, since its planes dip to west 20° north, at an angle of 30°, between Bala and Llangynnog, while they curve round so as to dip to north or to north 5° east at various angles in the country south of Llangollen.

The dip of the cleavage is not so regular as its strike, inclining sometimes to one side and sometimes to the other of the line of strike, and varying almost indefinitely in the amount of inclination.

The south of Ireland is traversed by a cleavage which strikes almost invariably east 25° north, and west 25° south, dipping either way at various angles in different places. Not only are the argillaceous rocks frequently affected by it in Ireland, but in many places fine sandstones also, and even coarse sandstones and conglomerates, are split by it into rough slabs, or show dog-toothed indentations parallel to it at the tops and bottoms of their beds. In County Cork even thick beds of limestone are often so affected by it as to be

spoilt as marbles, or as decorative building stones, from having a tendency to split into a kind of limestone slate, with thin seams of clayey matter often showing on their surfaces.

Cleavage occurs usually in districts in which the rocks have been much disturbed and much indurated, though it is not perhaps an invariable accompaniment of disturbance and induration. Neither in cleaved districts does it occur everywhere; spaces appearing sometimes to be free from it although surrounded by others of like character that are affected by it.

The effect of cleavage on embedded fossils is especially remarkable, these being distorted and lengthened in the direction of the cleavage planes, and contracted in the opposite direction. A similar distortion is also seen in Fig. 29, where the lower laminæ are contorted more than the upper, the former having been probably harder than the latter, and incapable of being squeezed into the same space without more contortion and extension lengthways.

The cause of slaty or transverse cleavage is now generally believed to be great mechanical pressure in a direction at right angles to that of the cleavage planes. Dr. J. Tyndall has actually produced a cleavage in wax and other substances by a lateral compression.

Foliation.—There are sometimes found on the surfaces of clay-slates, when first split open in the quarry, semi-crystalline flakes of chlorite or other mineral substances differing somewhat from the ordinary clay-slate on each side of them; and this is carried out to a

still further extent in other rocks which "separate into crystalline layers of different mineral composition." The rock is then said to be *foliated* (from *folium*, a leaf).

Foliation, however, does not necessarily coincide with cleavage; and, indeed, in Scotland it is almost invariably coincident with the original stratification, the rocks perhaps never having been cleaved. But if rocks already cleaved are acted upon by any agencies tending to metamorphose them and re-arrange their particles in separate folia, that re-arrangement may in some cases take place along the cleavage planes, and in others along those of original lamination.

Foliated rocks, although they are now at the surface of the ground, where alone they can come under our observation, can nevertheless be proved to have been once deeply buried in the earth, and therefore to have been subjected to a greater pressure and a higher temperature than that which prevails at the surface. Let us suppose rocks, originally wet muds and sands, to be ultimately covered by many thousand feet of other similar beds, in consequence of the long-continued depression of the sea bottom on which they were deposited, and the repeated deposition of other beds over it. Then let us suppose that, after remaining stationary for another great period, that part of the crust of the earth begins to suffer from an accession of heat derived from the interior, and is affected by a slowly acting force of elevation, accompanying that heat, or caused by it—the heat and force varying in intensity perhaps in

different parts of the area, or during different times of the long-continued process. The consequence of such a process must be that the more deeply seated portions consisting of various mineral substances, containing variable quantities of water, acted on by different degrees of temperature to an unknown extent of intensity, and certainly subjected to immense pressure, with various strains in different directions, and all continued through a vast period of time, must experience chemical influences unknown in our laboratories or only feebly to be imitated in them.

Thus it appears that foliation is the result of a long series of actions, perhaps the most important agents being pressure and heated water charged with alkaline solutions. The great force which has compressed whole mountain chains and produced cleavage may in some cases have generated heat, and set to work a chemical action in the rocks which compose them, tending to alter their chemical composition, as well as their physical structure. Mr. Sorby brought these facts under the notice of the Geological Section of the British Association at Cambridge, and pointed out the inevitable connection between the mechanical and chemical agencies. Warm water containing alkaline carbonates in solution, by percolating along the most marked lines of division in the rocks, whether stratification or cleavage, would decompose the substance of the rock, dissolving and removing some minerals and re-depositing others.

Metamorphic Rocks.—Mica and Felspar are the

two most abundant sources of clay, and Mr. Sorby has shown, by his microscopical investigations, that the particles of even the dullest clay-slate often consist more or less of pounded Mica. Very few clays are really pure, but contain iron and other substances, such as lime and alkalies, which would act as fluxes and facilitate their conversion back into Mica or Felspar. Most clays have some sand in them, consisting of quartz or silica, and if water be present this becomes soluble at no very high temperature, and fusible if lime or soda be near it.

Without attempting, then, to explain all the details of the operations that take place in the great internal laboratory that must exist in the deeper parts of the earth's crust, nothing appears more probable than that sands and clays which were in the first instance derived from the destruction of crystalline igneous rocks, may be eventually changed back into crystalline or semi-crystalline rocks of more or less identically the same characters as those they had before. The most important of these metamorphosed rocks are the following:—

1. *Marble*, or altered Limestone, of which there are many varieties of different colours and textures, but they are all fine-grained crystalline rocks, capable of taking a more or less perfect polish.*

2. *Serpentine.*—A compact rock, usually of a dull green colour, mottled with red or brown, and chiefly composed of hydrated silicate of magnesia. There are

* From this capability of taking a polish, the term marble has, in ordinary language, come to include all ornamental and polishable stones used in architecture and the kindred arts.

many varieties, some probably resulting from the metamorphosis of magnesian limestones, and others from augitic or olivine-bearing rocks.

3. *Slate.*—This has already been described under the head of Cleavage. Sometimes, however, clay or shale has been converted into a hard splintery rock, without cleavage, called *Hornstone;* it is often produced by contact with igneous rock.

4. *Quartzite*, Quartz rock, or altered Sandstone, a compact, fine-grained, but distinctly granular rock, which latter structure distinguishes it from vein-quartz. Quartz rock often forms ranges of lofty mountains, as among the Scottish Highlands.

5. *Mica-Schist.*—This consists of alternate layers of mica and quartz, the mica generally formed of a number of small flakes firmly compacted together, and the quartz more or less closely resembling vein-quartz; many varieties, however, contain only little quartz. Mica-schist often has a minutely corrugated or crumpled structure. The original rock before its alteration was probably a more or less sandy mud.

6. *Gneiss.*—This rock is composed of the same minerals as granite—viz. quartz, felspar, and mica; but they are arranged in irregular lenticular layers, giving a schistose texture to the mass. Some gneiss, indeed, might be termed schistose granite, and in Ireland it has actually been traced passing into true granite. In fact, large masses of rock which are lithologically Granite, are geographically nothing but Gneiss—having been formed *in situ*, from the partial or complete fusion,

at a great depth, of other rocks which contained the elements of Granite. This metamorphic or Gneissoid Granite often differs somewhat in mineral composition from true irruptive Granite, being more basic, containing Oligoclase as well as Orthoclase, Black-mica only, and perhaps less Quartz than the other.

It is from this cause probably that much of the uncertainty has arisen as to the origin of Granite which has given rise to disputes on the subject. The specimens examined by many Chemists and Mineralogists were not perhaps derived from masses of genuine intrusive Granite of directly igneous origin, but from masses of this re-formed Granite. It is possible perhaps that the two kinds of Granite may be hereafter distinguishable by their mineralogical characters or chemical composition, but at present the geologist is in the best position to pronounce on them by means of a careful survey in the field, and by determining their "*behaviour*" with respect to the surrounding rocks, or the nature of the relations between the two.

The following is a list of Metamorphic Rocks :—

LESS ALTERED	MORE ALTERED.
Altered Limestone.	*Serpentine.*
Some Dolomites.	*Mica-schist.*
Clay-slate.	*Hornblende-schist.*
Hornstone.	*Gneiss.*
Quartzite.	*Protogene and other Metamorphic Granites.*

Section II.—Concretions and Veins.

It is not, however, only in those rocks that have once been buried deeply in the earth that subsequent changes in mineral structure and composition have taken place. Great alterations sometimes occur which are quite independent of any causes outside the rocks themselves, but arise from molecular changes in the substances of which they are composed.

Other modifications have been produced by the metamorphic agencies, which have been briefly referred to at pages 84 and 122, viz. the percolation of cold water from the surface, and the uprising of warm water from below charged in both cases with mineral solutions.

Lastly, even during the process of formation and deposition of beds, and certainly before their consolidation, chemical reactions sometimes take place, which result in the development of what are ordinarily called concretions; and though such nodules can hardly be classed under the head of metamorphic changes, yet it will be convenient to consider them here. Concretions then may be formed in several ways, either by molecular attraction, or by deposition from solution in water, or by precipitation from solution through chemical action; the latter process being generally synchronous with, and the two former more or less subsequent, to the formation of the bed containing them. We may therefore consider concretions under the following heads:—

I. Contemporaneous Concretions. (*a*) *Organic.*— Those nodules which have been formed during the

deposition of the rocks in which they are embedded are due in almost all cases to the decomposition of organic matter, the resulting gaseous and liquid elements having caused the precipitation and concentration of various substances which were held in solution by the water above. Flint and chert nodules, the so-called coprolites or phosphate nodules, and many iron-pyrites lumps, are concretions thus formed, and often enclose remains of the organism which produced them ; hard clay, flint, or pyrites are also found filling up the interior of fossils, which, had the process been continued, might have formed concretions. The similar mode in which other concretions occur suggests for them the same origin ; such are clay-ironstone balls and septaria nodules ; but these may have been formed by chemical reactions independently of the presence of organic matter.

(*b*) *Igneous.*—The nodules sometimes found in Basalts and Greenstones were also formed contemporaneously during the cooling of the molten mass ; the jointed columns of the Giant's Causeway and other places (see ante, p. 142, and Lyell, *Stud. Elem.*, p. 496) present the effects of this concretionary structure carried to its full extent. Felstone and Granite occasionally also exhibit instances of nodular structure.

II. Subsequent Concretions. (*a*) *Segregative.*—It was formerly thought that the mineral forming a concretion had once existed in a state of fine diffusion, but being drawn through the interstices of the surrounding rock by the force of chemical attraction, had segregated itself from all sides towards a centre. Crys-

tals and nodules of Selenite, Galena, Iron pyrites, etc., must probably be explained in some such way, but most concretions can now be attributed to other causes. Some Dolomites of Magnesian limestones, however, present a structure implying subsequent movements in their component particles, the rock

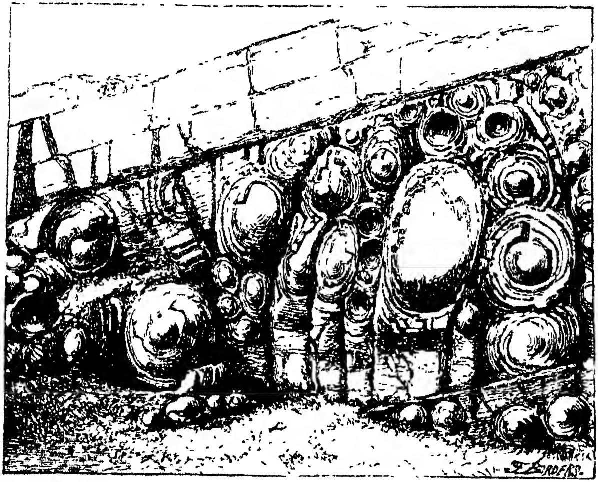


Fig. 30.

Sketch of Coal-measure shale weathering into spheroids, in a railway cutting near Mallow, County Cork, taken from the "Explanation" of Sheet 175 of Maps of Geol. Survey, Ireland.

assuming the form of bunches of grapes, piles of cannon balls, or clusters of oval nodules, generally with a radiating crystalline structure internally, the lamination or lines of deposition running through all the rock quite independently of these forms.

Some shales in the south of Ireland exhibit a very curious structure, the whole rock separating into spheroids, some of the larger ones decomposing in concentric coats, and including a smaller ball, as shown in Fig. 30. Volcanic ash sometimes presents similar instances of spheroidal structure. Oolite and Pisolite are also composed of small concentric concretions, often including a minute particle as nucleus. For a possible mode of formation of these rocks, see p. 70.

(*b*) *Infiltrated.*—Other concretions have been formed by the deposition of material from solution in previously existing hollows; to this class belong the amygdaloidal concretions in igneous rocks, of calc-spar, agate, chalcedony, and other precious stones; and lastly the lumps of hæmatite in limestone, which sometimes form regular beds of iron. These were all gradually deposited from solution in water as it percolated through the rock, and this dissolving agent has probably been conducive to the formation of all other subsequent concretions.

These infiltrated concretions have so much analogy with mineral veins that the latter naturally follow as the subject of our consideration.

Veins.—(*a*) *Non-metalliferous.*—Most hard rocks are traversed by small cracks running in various directions, and filled with some kind of spar. A vein or veining is in many cases only a thread of an inch or two in length, and may be regarded as merely an elongated concretion; others are larger and longer, often branching and splitting up into small tortuous strings; occasionally they are of considerable size, as

much as two or three feet in width, and many yards in length.

The spar found in these veins is usually calc-spar in limestone rocks, and quartz in all siliceous rocks; other minerals sometimes occur, but rarely in comparison with these two. It is clear then that the spar which fills these veins was derived from the adjacent rocks by solution, and deposited in the veins by crystallisation. The numerous caverns also which occur in limestone rocks are sometimes partially or wholly filled up with calc-spar, with or without crystalline deposits of galena (sulphide of lead) and other substances.

(*b*) *Lodes or Metalliferous Veins.*—In some districts other veins occur, which are called mineral or metallic veins, and sometimes lodes. A true lode is in reality a fault or fissure caused by fracture, in which open spaces have been left for a time because of the hardness of the walls and the irregularity of the fracture. These fissures have subsequently been filled up with crystalline deposits of various minerals, of which those that contain mere earths or useless metals, such as calcium, are called spars, while the compounds of the more useful metals, such as zinc, lead, copper, silver, and gold, are called ores. Iron ore sometimes occurs in lodes, but is much more often procured from beds or from veins of a different character.

True lodes sometimes resemble in their form dykes of igneous rock, but they may be at once distinguished from them by the nature of their contents, and by the difference in their relations to the surrounding rock.

By what processes the various minerals have been introduced into veins and lodes is a question about which, until lately, very little was known, and much still remains to be learnt.

Some persons have supposed them to have been filled by minerals sublimed from the interior of the earth; it is impossible, however, to separate the origin of the ores from that of the spars in which they are entangled and embedded, and as these are chiefly quartz and other substances to which we cannot attribute an igneous origin, it is equally difficult to refer the ores to that source. Many other considerations might be adduced in favour of the supposition that the contents of mineral veins were in some way derived, through the influence of water, from the very rocks which they traverse.

Sir H. de la Beche has pointed out that warm springs, like those of Bath, are probably fed by water rising from great depths through narrow fissures; and as this water must lose a great amount of heat before arriving at the surface, it would gradually deposit those substances which are only soluble at high temperatures, such as silica, retaining only the more soluble matters, such as the salts of soda and potash, and carrying them to the surface. Gradual deposits of this kind would result in the closing up of the fissures and their conversion into mineral lodes.

From the facts we have learnt in this and previous chapters regarding the passage of water above ground and under-ground, we perceive that not only is there a

circulation of water above the surface of the earth, through clouds, rain, rivers, and sea, but also a circulation below the surface, through what we may consider as descending and ascending streams of water. The two circulations are further similar in that their primary action is that of dissolution and removal, their final result that of formation and re-deposition ; from another point of view, however, their results are widely contrasted, for while to the one set of agencies we attribute the production of most of the strata composing the earth's crust, it is to the latter system of operations that most of the subsequent changes observable in their structure are due.

CHAPTER XIV.

FOSSILS AND THEIR MODE OF OCCURRENCE.

It has been stated in some of the preceding chapters that the crust of the earth is principally composed of stratified rocks, which were formed under water. These were, of course, chiefly formed in the sea, though some smaller parts were deposited in the beds of lakes or at the mouths of rivers. In whatever water they were formed, it is to be expected that these deposits would from time to time enclose the bodies of some of the animals and plants that lived and died in the water, and occasionally even some of those which were swept into it from the land. We saw in Chapter VI. that marine limestone was derived from the fragments of animals, and that coal was formed by the decomposition of plants. Many sea animals burrow into mud and sand, and live there habitually; and the dead bodies of others must be occasionally buried in such deposits. Some of the animals and plants, or their fragments, thus buried in the sediments which were afterwards hardened into rock, would doubtless decompose, and leave scarcely any trace of their presence. Of others, however, the form or impression of the body

would be retained in the substance of the rock, or even the body itself might be preserved.

Petrifaction.—This preservation might be effected in two ways. By the first, the decomposition of the body is simply prevented, more or less completely, so that the body remains, more or less entirely, in the same state that it was when it was first buried. If the enclosing substance be a very fine pure clay which does not itself contain any active chemical substance, and does not allow of the percolation of water, and if the body, when buried, consisted of only one substance, that would remain inactive so long as it was left to itself, the conditions for such a preservation would be most complete. Shells, with all their nacreous lustre and iridescent colours, are found in clays of very ancient date, so ancient that, if stated in years or centuries, an indefinite number of millions of either would have to be assigned to them. Wood, so little altered as to be still in the state of wood, easily scratched or indented with the nail, is found in similar clays. In some very ancient shales fragments of leaves may be found that, when first laid open, retain a greenish tint, and are semi-transparent, and have the dampness of vegetation upon them, although a few minutes' exposure to the air suffices to wither them into decay.

The second method of preservation of bodies is that called petrifaction, by which the organic substance loses more or less of its organic structure and composition, and acquires those belonging to a mineral. Some shells buried in clays have lost the carbonate of lime,

of which they were originally composed, and now consist of iron pyrites, or some other mineral. This replacement of one mineral substance by another, however, has taken place so gradually, particle by particle, that the external form, and even the most delicate markings and minutest structure possessed by the original shell, are retained in the new substance. Shells or other calcareous bodies buried in calcareous mud are commonly petrified by the addition of some of the same substance as that originally composing the shell or test, Calcite or carbonate of lime filling up the interstices, and taking a crystalline structure instead of the cellular one which was that derived from the animal. Sometimes, however, an organic body buried in limestone is changed into flint, especially if it contained some silica in its original composition.

In sandstones, which commonly allow of the free percolation of water, it is more usual to find only casts or impressions of the bodies enclosed in them, the substance of the body itself having been dissolved and carried away by water. These are often merely external casts, the outside of the body having left its mark in the enclosing rock; and this impression is sometimes so faithful as to show the most delicate striæ or wrinkle in the original form. Sometimes the inside of the body itself was filled either by fine mud or by some crystalline mineral, before it decomposed, so that a cast of its interior is left, with all the muscular impressions or other internal marks which the recent body could have displayed.

Traces even of the skin, or soft parts, of animals, and of the most delicate venation of the leaves and stems of plants, are sometimes preserved in these impressions. The scaly coats of fish are often retained, almost as perfect as if taken freshly from the animals; while teeth and bones are obviously as indestructible as shells, and, being composed like them chiefly of salts of lime, will obey the same laws of petrifraction.

Even the tracks or footprints of animals crawling or walking over sand in shallow water, or on the sea-shore at low tide, are preserved on the surfaces of some flag-stones in the most wonderful way, as also the holes and burrows of annelids or sea-worms.

A footprint, especially if it be covered by a little film of clay before the next layer of sand is tranquilly deposited on it, will be as likely to be retained unaltered as any other form, and will give us as sure an indication of the existence and character of the animal as did the footprint on the shore of the desert island to Robinson Crusoe, which assured him that a strange man had passed that way.

In a similar manner plants may be petrified; either by being altered into coal, through the abstraction of their gases, so that the residue becomes more and more nearly pure carbon; or by the replacement of their particles, some other mineral matter, such as carbonate of lime or silica, taking the place of the carbon. The woody stem will then become limestone or flint (wood opal), in which, perhaps, all the fibrous and cellular structure of the original wood may be retained in

consequence of the minuteness of the particles which are gradually abstracted and replaced.

The mere amount of change, then, which the fossil has undergone, is not by any means a proof of the length of time that has elapsed since it was buried in the earth; as that amount depends so largely on the nature of the material in which it was entombed, and on the circumstances that have since surrounded it. Some of the most ancient fossils may be very little petrified, some of the most modern may be completely so. Nevertheless, since the longer a body is buried the more chance it has of being acted on by those conditions which conduce to petrifaction, it follows that the majority of the most recent fossils are less altered than the majority of the more ancient ones.

But it may be asked here, if the antiquity of a fossil is not to be judged of by anything in the state of the fossil itself, how is it to be determined? The answer to this is that the age of a fossil can only be known, in the first instance, by that of the beds in which it is found; and the relative antiquity of the beds can only be determined by their relative position.

Distribution of Fossils in Stratified Rocks.—We know that in the seas of the present day different animals frequent different places; some love clear open water, some muddy or sandy shores, some live in the deep sea, some only in shallow water. We should expect then to find a difference in the kinds of fossils in different rocks; some kinds occurring chiefly in old indurated muds, some in sandstones, others in lime-

stones. If, however, the animals were free swimmers like fish, or if the body floated after death, or the fragments of it were carried far by currents, the nature of the bottom where it came to rest and was buried would have no connection with the habits of the animal. So of plants and animals carried from the land into the sea, they might float far and be entombed in any kind of rock; still, as sands and muds are generally formed more near to the land than limestones are, we should expect more often to find land plants or animals in the former than the latter. We have here one set of circumstances bearing on the distribution of fossils.

Another arises from the geographical distribution of animals and plants. The mud and sand forming round the shores of the British Islands now cannot contain precisely the same shells as those which are forming in the Mediterranean, or round the coasts of the West Indies, or the Cape of Good Hope, or Tasmania, or Tierra del Fuego. The molluscs and other animals now living in the seas of these places are almost entirely different, no two of them having the same assemblage of species, and some of them not a single species in common. So in past ages of the globe, the fossils which were deposited at the same period in widely different parts of the earth would be different from each other. If they were not it would be a matter for surprise on our part.

These facts show us that fossils will probably observe what may be called a *lateral distribution*, and that beds formed at the very same time will not always con-

tain identically the same fossils, and that even the very same continuous group of beds may vary in this respect. For when we come to trace groups of beds across wide countries, we find that the same group often varies, so that, consisting almost entirely of limestone at one place, it will in another perhaps contain little or no limestone, and be made up almost, or altogether, of clay, or sandstone, or both. The very same sea will have the waste of the land swept into it from one side, while at a greater distance from the land limestone only may be formed.

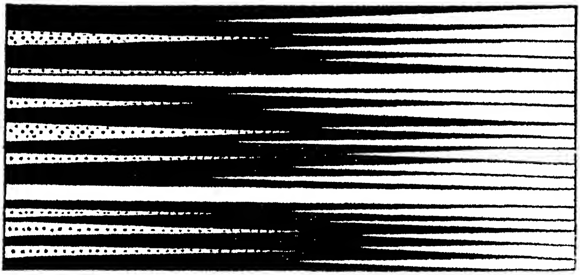


Fig. 31.
Lateral Changes in Beds.

Fig. 31 may serve as a diagrammatic representation of the way in which a lateral change may take place in a group of beds; the white bands being supposed to be limestones, the dotted ones sandstones, and the black, clays. This, however, is a mere diagram, and not a representation of nature, for each natural bed is in reality a great cake, thinning out gradually at the

edges all round. It would require a diagram of some feet in length to represent accurately the way in which the changes really take place. Instances of these changes are known even within the British Islands, and will be described farther on.

There will naturally be a difference in the assemblage of fossils collected from the limestone end, marked A in the diagram, and those got from the end marked B, although the fossils may be alike in each bed throughout its extension.

Vertical Distribution of Fossils.—The fossil corals, shells, scales, bones, teeth, and other hard parts of animals, have now for many years been the subject of careful examination and comparison by many of those men, in all countries, who were best acquainted with the corresponding living animals. The fossil leaves, roots, and stems of plants, have in like manner been examined by some of the best botanists of all countries. The conclusion they have all come to, is that the remains found fossil in the stratified rocks belonged chiefly to species which were different from any now living on the globe. Some of them are merely *extinct species* of genera which have other species now living; extinct species of oysters or cockles among shells, extinct species of crocodiles or turtles among reptiles, or elephants or rhinoceroses among mammals. Others, however, are so different from any living animals, that new *generic* names have to be invented for them, and there are even groups of such extinct genera making *families*, or even in a few cases *orders*,

which are distinct from any of the living orders of animals.

If, however, we were simply to take fossil animals and plants on the one hand, and living ones on the other, classing all the fossil ones together indiscriminately, we should lose sight of the most interesting and important facts which are to be learnt from them. Fossils do not occur indiscriminately ; not only do they differ, as previously mentioned, according to the kinds of rock, and according to the different parts of the world in which they are found, but in the very same country, and in rocks of precisely the same mineral character, a law of distribution is observable in fossils according to the order of superposition of the groups of stratified rock in which they occur.

The diagram, Fig. 32, will serve to illustrate this. Let it be supposed to represent a great longitudinal section across a country of several miles in length. Let this section disclose three groups of stratified rocks, A, B, and C, each made up of limestones indicated by the plain bands, of shales marked by continuous lines, and of sandstones dotted by broken lines. Let us also suppose that all the beds contain fossils. The group A will have certain kinds of fossils in the clays which we may call the *a* fossils, certain others in the sandstones which we may call *b*, and certain others in the limestones which we may denote by *c*. Throughout this group A the same fossils may always be found, in beds of the same character, from top to bottom, all the limestones containing the same *c* fossils, all the sandstones

those called *b*, and all the clays those called *a*. Occasional intermingling of the kinds may occur, and there may be other fossils which occur indiscriminately throughout all the beds of the group A, still the general tendency will be towards the state of things thus described. When, however we pass from the

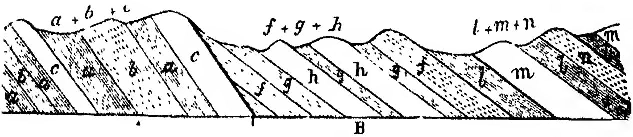


Fig. 32.
Vertical Distribution of Fossils.

group A to the group B, we shall find an entire change in the kinds of fossils. The group B may also have its sandstone fossils *f*, its clay fossils *g*, and its limestone fossils *h*, but all these fossils will be distinct from those found in A. In like manner the group C may have, perhaps, its clay fossils *l*, its limestone fossils *m*, and its sandstone fossils *n*, but these may be every one of them different from those found in B or A. What conclusion must we draw from these facts? Each of the great groups of stratified rock found in the earth's crust being made up of sands, clays, or limestones, which are often absolutely undistinguishable from each other so far as the mere stones are concerned, and the circumstances of deposition being evidently essentially similar in all, the only conclusion we can come to as to the great distinction in their assemblages of fossils is, that the kinds of animals and plants found in the one

group—those called $a + b + c$ in group A, for instance, in Fig 32—were no longer in existence when the beds of group B were deposited, but had been succeeded by the kinds called $f + g + h$, and that these had likewise become extinct, and been succeeded by those called $l + m + n$, when the beds of group C were formed.

Gradual Introduction of Species.—The sudden changes which often take place in the fossils after passing one of the boundaries of the different groups of rocks, cannot be held to prove that the destruction of one assemblage of organic beings and the introduction of another set was in itself a sudden act. It was shown in Chapter IX. that the interval which elapsed between the formation of two consecutive beds of rock can often be proved to have been a very long one, and may, in most cases, have been of any imaginable length of duration. The fact that one bed now rests upon another merely proves that nothing was deposited between them, or, if there was anything deposited, that it was removed again. As long a period of non-production may have elapsed in the interval as sufficed for the deposition of many thousand feet of beds in another place.

When we have a great series of beds containing many similar fossils throughout, it not unfrequently happens that a few species occur in the lower beds, which become scarce or disappear in the upper ones, while new species appear in the upper beds which are not found in any below. These facts, joined with the difficulty of imagining any means for the rapid exter-

mination of a widely diffused species, prove it to have been always a slow and gradual process. In like manner, however, we may suppose new species to have originated, the multiplication and diffusion of the individuals over large areas must be a slow and gradual operation.

Those individuals, of which the remains are found in the stratified rocks, were merely a few caught from time to time in the partial and local sediments that happened to be thrown down here and there, at the bottom of seas or lakes, under circumstances favourable for their preservation, and we must not, therefore, be surprised at finding many gaps and breaks in the succession of life which the history of the rocks reveals to us. No argument, then, can properly be based merely on the absence of the remains of organic beings which were intermediate in details of structure between those that we do find.

In contemplating the vast periods of geological time, they often appear to diminish in proportion to their remoteness, just as vast distant spaces dwindle in the eye. If we could visit one of the nearest fixed stars and still see the earth, the space between it and the sun would appear to be nothing, and our little globe would seem to be rubbing against the greater luminary as it revolved round it. The ninety-five millions of miles, seemingly annihilated in the one case, are only a fair image of the ninety-five millions of years that elude the grasp of our mental vision in the other.*

* Sir W. Thomson, however, thinks there are data for assigning a limit to geological time, and he is inclined to fix this at 100,000,000 years.

PART III.

The History of the Formation of the Earth's Crust deduced from the Facts observable in it, as interpreted by the Processes now in operation.

CHAPTER XV.

GEOLOGICAL HISTORY.

In the first chapters of this little book a sketch was given of those natural processes now in action upon the earth which could either add to or modify the structure of its crust.

The succeeding chapters were devoted to a description of some of the principal facts to be observed in the examination of that structure.

It remains to apply the knowledge thus gained to the construction of a history of the formation of the crust of the earth. As, however, any attempt to extend this history to the whole earth would lead us to a length far greater than our limits will allow, we must here confine ourselves to an account of the formation of that small part of the earth's crust which includes the British Islands.

A reperusal of Chapter X. will enable us to see at once how a knowledge of the geological structure of the British Islands may be gained by a sufficient extension of the investigations there described. Numerous geological maps and sections and descriptions have been published during the last 60 years, at first proceeding from the public-spirited labours of individuals and scientific societies, but aided during the last 30 years by a regularly constituted Geological Survey, paid out of the public funds, and conducted under the authority of an Act of Parliament (*8th and 9th Victoria, chap.* 63). These delineations, which were necessarily imperfect at first, are daily being corrected and enlarged, so that the history constructed from them has every now and then to be rewritten with the necessary amendments. Old readings have to be revised, former errors of interpretation to be corrected, new chapters now and then to be interpolated, events at first supposed to be widely separated in time are afterwards found to have been more or less contemporaneous, and separated perhaps only by space, while other events formerly supposed to be closely connected in time have to be referred to widely different eras.

This, however, is what takes place in all human histories of past events, and so far from invalidating them only strengthens their authority. Skill in reading and interpreting old human documents is acquired and extended by experience and use, and the skill of the few "experts" becomes greater in proportion to the number of persons who are able to criticise and judge

of it. Exactly the same increase of skill takes place amongst geologists in the reading and interpreting those documents (or *teachings*) which the crust of the earth unfolds to us in the rocks of which it is composed.

There are many other analogies between geological history and that of any nation. In the history of a people, for instance, it usually happens that most difficulty is found in tracing their beginning, both from the fewness of the documents and the difficulty of their interpretation ; the parts into which human history can be divided are also very often separated by mere blank periods of darkness and barbarism, of which no trustworthy records remain to us. In all human histories that which is written is but a brief abstract of that which happened. How much even of what is recorded in our daily papers will appear in history 500 years hence ? the answer will show us how much less we have of the history of 500 years ago, when there were no public journals.

Geological history must needs be far more deficient than that of nations. It has literally no beginning ; it commences with a few scattered, half-obliterated documents, which only show us that something happened before, like that which has occurred since. It is separated into parts by great intervals, of which not only have no records been discovered, but no evidence even as to the length of the intervals.

Singularly interesting and useful then as geological history may be, we must carefully bear in mind its imperfect and fragmentary character.

What we actually learn from it is true, but we must recollect that it is not all the truth, and that as "*all the truth*" about anything whatever is absolutely unattainable by us, it would only lead us astray if we required it from Geology, or reasoned as if we had obtained it.

Division of Geological Time.—It has been found convenient to divide all Geological Time into three great Epochs, called Primary, Secondary, and Tertiary. It is obvious that we may speak of the rocks deposited during these respective Epochs as the Primary, Secondary, and Tertiary rocks. It was at one time thought that there was some original essential distinction in the nature of these rocks and their mode of formation. It is now known that the Primary rocks, when first formed, were exactly like the corresponding Secondary and Tertiary, or like those now forming on the globe, and that any peculiar characters they may have in the way of hardness, slatiness, or crystallisation, are due to subsequent modifying influences.

In order to get rid more completely of the old notions that clung to these terms, geologists have lately been in the habit of using for them those proposed by Professor Phillips—namely Palæozoic, Mesozoic, and Kainozoic. Palæozoic, meaning "*ancient life*," answers to the term Primary; Mesozoic, or "*middle life*," to the term Secondary; and Kainozoic, or "*recent life*," to the Tertiary. The term Neozoic (new life) is sometimes used for the two latter taken together.

Each of these epochs is subdivided into periods, and each period was occupied by the formation of a certain group or series of stratified rocks.

The whole history is based upon the observed fact that these groups of beds rest successively one upon another; and the following tables give the names which have been assigned to these formations, or rather to the periods during which they were deposited.

The first table or list gives no idea of the relative importance of these periods, and might even lead the student to suppose that they represent equal amounts of time, and include nearly equal thicknesses of strata. Such, however, is by no means the case, and in order to correct any such impression, the second tabular view has been given, and may be taken as exhibiting a vertical section through the British Sedimentary rocks, on the scale of 16,000 feet to an inch, and expressing the approximate relative thicknesses which the several formations attain in this country.

A glance at this table will show how greatly the mass of Palæozoic rocks preponderates over those belonging to the Neozoic periods; the Silurian strata alone being thicker than the Secondary and Tertiary series put together. Again the three latest groups are of so little stratigraphical importance that they cannot be separately represented in the diagram.

The successive periods are in fact to be considered merely as arbitrary divisions which have already been considerably altered and adjusted, and will probably require still further modification during the progress of geological knowledge.

TABLE I.

Tertiary or Kainozoic Epoch.

14. Pleistocene period.
13. Pliocene period.
12. Miocene period.
11. Eocene period.

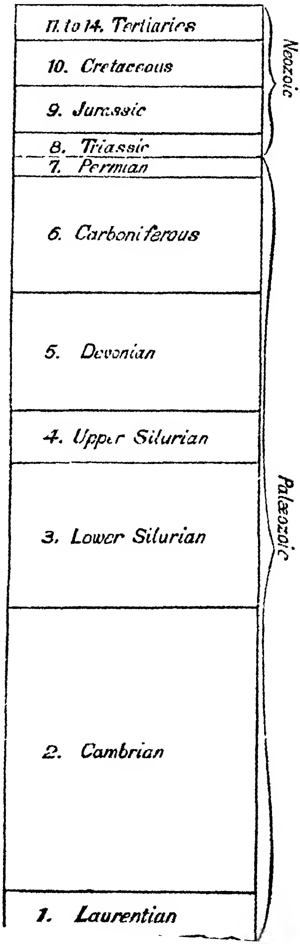
Mesozoic or Secondary Epoch.

10. Cretaceous period.
9. Jurassic period.
8. Triassic period.

Palæozoic or Primary Epoch.

7. Permian * period.
6. Carboniferous period.
5. Devonian † period.
4. Upper Silurian period.
3. Lower Silurian period.
2. Cambrian period.
1. Laurentian period.

TABLE II.



* Regarding the allocation of ιis period, see note on p. 272.

† The Author held views with ·gard to the propriety of this eriod, which differ from those ιken by most geologists, and ıe question cannot yet be re- ırded as settled.

The irregular line at the base of Table II. indicates that the thickness of the lowest or Laurentian group has not yet been ascertained in Britain. Geological history can only begin like a fairy tale—"Once upon a time there was a sea, and in that sea certain rocks were formed," and so on; it is by no means the first time of all, since as to that we know nothing.

Geological Nomenclature.—On looking over this list of names for the first time, many of them will doubtless seem to be rather odd appellations for periods of time. That circumstance, however, need not trouble us any more than the odd names of persons that occur among ourselves. Names in general originate as *descriptive* appellations, and apply peculiarly to the person or thing to which they are first affixed. They are, however, continued or extended to other persons or things related to the first, in some way that makes the retention of the name necessary, although it is no longer applicable as a description, and sometimes ridiculously inappropriate. John Short does not change his name because he is over six feet high, nor Thomas Long if he happens to be five feet nothing.

So, in geology, if a group of rocks happen to consist of red or green sandstones where first examined, and are therefore called the Greensand or the Red Sandstone; and if, as they are followed into another district, they gradually pass into dark clay or white limestone, they sometimes still retain the old name as a group.

Thus the Chalk or Cretaceous rocks of Western Europe in other parts of the world have no chalk in

them at all, and consist, in some countries, of sands and clays with beds of bituminous coal, and in other regions of clay-slate. The retention of the name Cretaceous for such groups is necessary, to show that they are contemporaneous, or rather *homotaxial*,* with the chalk beds of the locality where that group was first examined.

The diagram on p. 196, illustrative of the lateral changes in the composition of beds, will perhaps make this clearer. Suppose that where a group of rocks was first examined and described, it had the limestone character as at A, and that it preserved this character over an area several scores of miles across in length and breadth, and that it was called by a certain name, say "Carboniferous Limestone," which became its commonly received designation. If the group were afterwards traced in the direction where it gradually changed from a limestone formation into a clay and sandstone one, we should be obliged either to continue to call it the "Carboniferous Limestone," notwithstanding there was little or no limestone in it there, or give another name to this part, and so have two names for the same group, or else to get the name of the "Carboniferous Limestone" altered into something else, even in the districts where it did consist of limestone.

* Homotaxis (*similarity of order*) is a word introduced by Professor Huxley to denote the relation between rocks in different parts of the world which occupy similar positions in the geological sequence, but which are not necessarily strictly contemporaneous, even though they may contain a similar assemblage of fossils.

But nothing is more difficult than to make men give up the use of a well-known and long-used name, so that the first alternative would probably be the one adopted, for a time at all events, and the name of the "Carboniferous Limestone" be applied to the group in all parts of its area, regardless of the actual quantity of limestone it contained in these parts, or whether in some there was any limestone at all.

CHAPTER XVI.

THE PRIMARY OR PALÆOZOIC EPOCH.

The Four earliest Periods, or those of the Lower Palæozoic Rocks.

In the study of the geological structure of the British Islands we should find that the general "dip" of the beds is towards the east or south-east. In travelling from the south-east to the north-west, therefore, we should meet with lower and lower rocks rising up to the surface as we proceeded. The undulations which occur in the beds in many places prevent this being true in every locality, but it is quite true on the large scale. The mass of the upper or Tertiary rocks are only to be found in the south-eastern parts of England; the Midland Counties are chiefly occupied by rocks belonging to the Secondary Epoch of geological time; while the lowest of the British Primary rocks only rise to the surface in Wales, in Ireland, and in Scotland, and the lowest part of these lowest rocks, only in the extreme north-western corner of the latter country.

Laurentian Period.

Fig. 33 is a diagrammatic section of a part of Sutherlandshire, and is taken from Sir R. I. Murchison's

papers in the Quarterly Journal of the Geological Society of London, showing three groups of rocks belonging to the oldest known periods of the earth's history.

This section is a very interesting and instructive one. The group *c* contains fossils which are known, from evidence elsewhere acquired, to have lived during the third or Lower Silurian Period of the list on p. 208. These rocks, therefore, are known to have been deposited during that period. Their beds rest unconformably on the previously denuded edges of those of group *b*, and those again on the edges of group *a*.

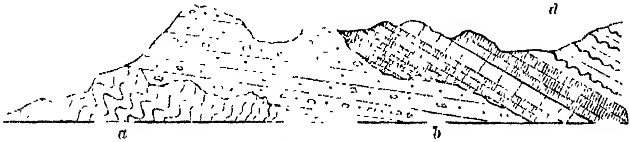


Fig. 33.

d. Crystalline, gneissose and micaceous flags.
c. Quartz rocks and limestone with fossils of Lower Silurian age.
b. Red Sandstone and Conglomerate 2500 feet thick, and believed to be of Cambrian age.
a. Grey hornblendic gneiss, with granite veins and greenstone dykes.

Group *a* consists of beds that have been altered from their original condition into a crystalline gneiss, and it appears from the section that this alteration must have taken place, and subsequent elevation and denudation have occurred before group *b* was deposited on them. As metamorphism can only take place at some depth in the earth's crust, or under a thick cover of other rocks, it is clear that that cover had been removed before the deposition of *b*. The group *b* itself, though not metamorphosed, had yet suffered greatly

from denudation before the period when *c* was deposited. If, then, the diagram, Fig. 33, be a correct representation of the facts, it leads us back to a dim antiquity of unknown periods before the time of our third period. We may vaguely speak of this ancient time, thus obscurely brought within the extreme verge of our mental vision, as belonging to the first and second periods of our list, but there is no real proof that group *b* does belong to the second period. All we can say is that it is older than the third. As good local names, not involving any chronological classification, we might speak of the group *a* as the Lewisian gneiss, and the group *b* as the Sutherlandshire red sandstone and conglomerate.

In North America Sir W. Logan and Mr. Murray have described a group of gneiss rocks like the Lewisian gneiss under the name of Laurentian gneiss, or that forming the basin of the St. Lawrence. Near Lake Huron the Laurentian gneiss is covered by a series of rocks called the Huronian series, which, like the Sutherlandshire sandstone, passes under rocks that contain Lower Silurian fossils, and therefore belong to the third period. The Huronian series, therefore, may be provisionally classed as possibly belonging to our second or Cambrian period, and the Laurentian gneiss as possibly of the same period as our Lewisian gneiss; Sir R. I Murchison indeed, in the last paper by himself and Mr. Geikie, considers the former as homotaxial with Sir W. Logan's Laurentian gneiss, and speaks of it by that designation.

The Laurentian series of Canada contains several thick beds of limestone, and in one of these the earliest known trace of life has been found in the shape of a large foraminifer, having a reef-like growth, and named Eozoon Canadense; other species have since been detected in the gneiss of Bohemia and Finland.

We do not see the Lewisian or Laurentian gneiss anywhere else in the British Islands, unless the oldest rocks at Malvern and St. Davids, and possibly even those at Charnwood and in Donegal, are of this age; so that we may now dismiss the præ-Cambrian formations, and come to those which succeed them.

The general succession of the great series of strata forming the Cambrian and Silurian periods has been established for some time, having been originally worked out by Prof. Sedgwick and Sir R. I. Murchison. The more recent labours of Prof. Ramsay, Dr. Hicks, and others, have also greatly aided in determining the limits and mutual relations of the several formations composing this long series; but the relative extension of the two periods Cambrian and Silurian respectively, and the precise arrangement of the minor groups under these two heads, is still a matter of controversy. The classification here adopted is substantially the same as that proposed by Prof. Phillips and followed by Lyell and Hicks. The succession of the beds is given below, and the arrangements originally proposed by Sedgwick and by Murchison are compared with that of Prof. Phillips,

which only differs from that now adopted in the allocation of the Arenig group.

Formations.	Sedgwick.	Murchison.	Phillips.
Ludlow beds - -	Silurian.		
Wenlock beds - -			
Upper Llandovery -			
Lower Llandovery -	Upper Cambrian.	Lower Silurian.	Lower Silurian.
Bala series - -			
Llandeilo flags - -			
Arenig group - -	Middle Cambrian.		Upper Cambrian.
Tremadoc slate flags - -		Primordial Silurian.	
Menevian beds - -	Lower Cambrian.	Cambrian.	Lower Cambrian.
Harlech grits - -			

CAMBRIAN PERIOD.

Geographical Distribution.—Rocks belonging to this period are found in North and South Wales, in Shropshire, in the S.E. of Ireland and the N.W. of Scotland. In North Wales the rocks are exposed in frequent glens and precipices and along numerous hill-sides, as well as in large and abundant quarries, so that they can be well examined. The rocks which thus rise here and there from beneath all the others in North Wales, and form the foundation of the country, may well be called the Cambrian rocks, and the period during which they were deposited may be spoken of as the Cambrian period. The series of strata included under this denomination are divisible into an upper and a lower portion, for reasons which will appear presently.

Section I.—Lower Cambrian.

Harlech and Longmynd Series.—The lowest beds to be found in the country rise to the surface in Anglesea, Caernarvon, and Merioneth, and also in a remarkable district in Shropshire. They are called the Harlech or Bangor beds, and are known to be the lowest, by simple inspection. All the other groups of rock may be seen somewhere or other to crop out and allow a lower group to appear from underneath them till we come down to this series, which rises to the surface in several places, but is never so completely exposed as to allow the base on which it rests to be seen, although a thickness of many thousand feet is shown in different places.

In Anglesea these beds are metamorphosed into chloritic and micaceous schists with quartz rock; granite rising up into them here and there.

In Caernarvonshire a good section of them may be seen in the sides of Nant Francon, the Penrhyn slate-quarries being worked in some of the upper beds. The metamorphism here has merely indurated the sandstones and cleaved the slates.

In Merionethshire these rocks form all that wild tract of rugged hills that rise to the east of the road from Barmouth to Harlech, and consist chiefly of thick gritstones penetrated by many greenstone dykes. (See section, Fig. 39, p. 227.)

In Shropshire the Lower Cambrian rocks form the hilly ground lying to the north-west of Church Stretton

and known as the Longmynd. Fig. 34 is a section across this range, reduced from the sections published by the Government Geological Survey. The Harlech or Longmynd rocks here consist of a great series of grey and blue and red sandstones, and shales, making an aggregate thickness of between 20,000 and 30,000 feet, the lower half being probably below the horizon of the true Harlech grits.

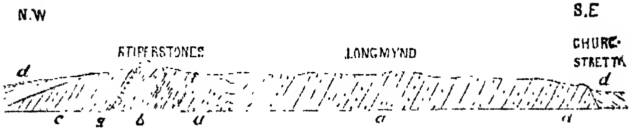


Fig. 34.

Section across the Longmynd, reduced from Mr. W. T. Aveline's sections. Length about nine miles.

d Upper Silurian beds, Llai very sandstone, and Wenlock she
c Arenig and Llandeilo seri
b. Lingula flags (Upper C:
a. Lower Cambrian grits an

In the south-eastern parts of Ireland great thicknesses of precisely similar rocks also rise from beneath all the rest, and are covered unconformably by those

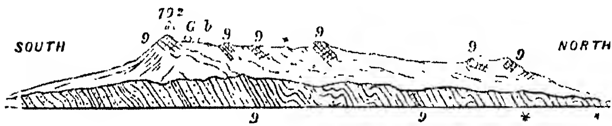


Fig 35.

Bray Head; length of section about 2 miles. 9, Quartz rock. *G b*, Granite blocks.

which belong to the third or Lower Silurian period. One of these districts is in the south of County Wex-

ford, the other in County Wicklow, Bray Head, ten miles south of Dublin Bay, showing a partial section of them. Fig. 35 is a rough representation of this, the lower part being intended for the cliff, and the upper for the slope of the hill above it.

Near St. David's, in Pembrokeshire, the rocks are well exposed, and have been investigated by Messrs. Salter and Hicks, who found a præ-Cambrian ridge of highly metamorphosed rocks overlaid by a fossiliferous series which are divisible into two groups—1, beds of grey and purple sandstone, equivalent to the Harlech grits, and which they denominate by that name; 2, an upper group of dark flags and shales 500 or 600 feet thick, which they call *Menevian*, from the classical name of St. David's. These latter rocks are also seen near Dolgelly, in Merionethshire.

Section II.—Upper Cambrian.

Lingula Flags.—The Menevian beds, both in Pembroke and Merioneth, are succeeded by a series of dark flags and slates which were first described by Mr. Davis and Professor Sedgwick. These are called the *Lingula flags*, from their abounding in many places with fossil shells which were formerly referred to the genus *Lingula*, but are now called *Lingulella*. In Merioneth they are between 4000 and 5000 feet thick (see Fig. 39), but become much thinner to the north and west in Caernarvonshire. In Shropshire they are again seen above the Longmynd rocks, as shown in Fig. 34.

Tremadoc Slates.—Under this name is included a group of dark slates which overlie the Lingula flags in their more southern exposures, being about 1000 feet thick in South Wales, and about the same at Tremadoc in Caernarvonshire, where they were first named by Professor Sedgwick. To the northward, however, they appear to thin out together with the Lingula flags, thus allowing the Lower Silurian to rest directly upon the Lower Cambrian rocks near Bangor.

Life of the Period.—A few traces of organic remains have been found in the Cambrian rocks of Wicklow, and some still slighter ones in the Longmynd. Fig. 36, *a* and *b* represent, on one-third the natural size, some curious starlike markings, called *Oldhamia*, after Dr. Oldham, with which some surfaces of the beds are entirely covered. They are believed to be the impressions of some kind of animal allied either to the Polyzoa, or else to the Sertularidæ of the present day. The Sertularidæ are compound polyp animals whose assemblage of cells is arranged on little branching stems and tufts. They are frequently seen on the sea-shore, and often erroneously spoken of as sea-weeds. The Fig. 36, *c* is a representation, on two-thirds the natural size,* of a small mound with a central hole and tube, of which several specimens were found at Bray Head by the late Dr. J. R. Kinahan. One of these, on being broken open, disclosed an elegant reticulation on the

* The fractional figures in the engraving indicate the scale on which the fossils are drawn.

surface of the internal tube and its cast, which was certainly produced by the tentacles of the animal that made the hole and mound; it was perhaps a creature

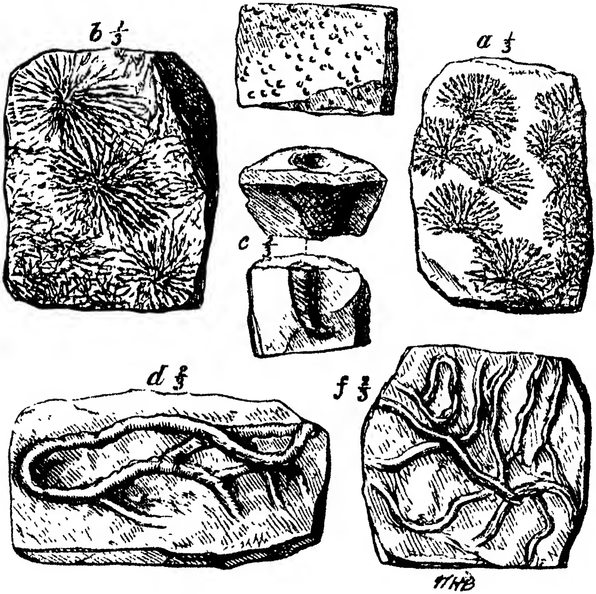


Fig. 36.
Lower Cambrian Fossils.

a. Oldhamia antiqua.
b. ——— radiata.
c. Histioderma Hibernicum.
d. Annelid? tracks.
e. Arenicolites didyma.
f. Molluscan? tracks.

allied to the present lob-worm. The other figures represent marks, probably caused by worms and other animals.

Until lately these few fossils from Ireland and Shropshire were the only known organic remains belonging to

this part of the series; the researches of Messrs. Salter and Hicks, however, in Pembrokeshire have brought to light abundant remains of Trilobites and other animals both in the Harlech and Menevian groups; among the fossils of the former may be mentioned *Conocoryphe*

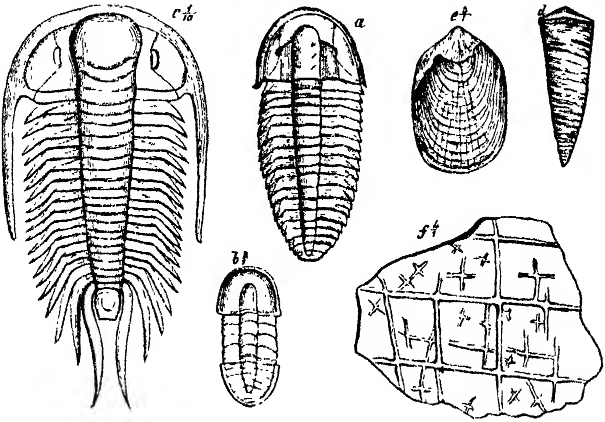


Fig. 37.
Lower Cambrian Fossils.

a. Conocoryphe Lyellii.
b. Microdiscus sculptus
c. Paradoxides Davidis.
d. Theca corrugata.
e. Lingulella ferruginea.
f. Protospongia fenestella.

Lyellii and *Microdiscus sculptus* (Fig. 37, *a* and *b*); these belong to the group of Trilobites, the former genus possessing a body made up of numerous segments, while Microdiscus has very few; the Conocoryphe figured is rather an elongated form of its species.

Conocoryphe (*cone-head*) Lyellii (*of Ly*
Microdiscus (*small disc*) sculptus (*scul*

Plutonia Sedgwickii is another Trilobite characteristic of these rocks.

The extinct Trilobita were more like the modern Isopoda or Woodlice than any other order of existing Crustacea. The head is formed of one large unjointed piece, as in our crabs and lobsters, while the body is made of a number of jointed rings or curved plates, which are conspicuous in the body of a lobster, and in what is commonly called the tail of a crab, which is always kept bent up close under the head. Some of the Trilobites also could curl up their bodies, as may be seen in Fig. 43, farther on. All their bodies are divided longitudinally into three parts or *lobes*, whence their name of Trilobite is derived. The eyes of the Trilobites are usually marked by a small semicircular or moon-shaped space on each side of the head, and over this eye-space is arranged a multitude of minute immovable lenses, so as to give vision in all directions at once. The lines which pass down near the eyes are called the *facial sutures*, and sometimes cut off the "cheek-pieces" from the rest of the head.

The Menevian beds have yielded more than 40 species, including some large Trilobites, especially *Paradoxides Davidis* (Fig. 37, *c*), which is nearly two feet long. *Lingulella ferruginea* was a brachiopodous bivalve shell, not differing much from the Lingulæ which are living in the tropical seas at the present day.

Plutŏnia (*belonging to Pluto*) Sedgwickii (*of Sedgwick*).
Paradoxĭdes (*the marvellous one*) Davidis (*of Davis*).
Lingulella (*little Lingula*) ferruginea (*rust coloured*).

Theca corrugata belonged to the class Pteropoda (*wing-feet*), consisting of small animals which float on the surface of the ocean. Fig. *f*, shows the structure of a kind of sponge called *Protospongia fenestella.* The following group, Fig. 38, contains some of the fossils which characterise the Upper Cambrian beds of Wales :—

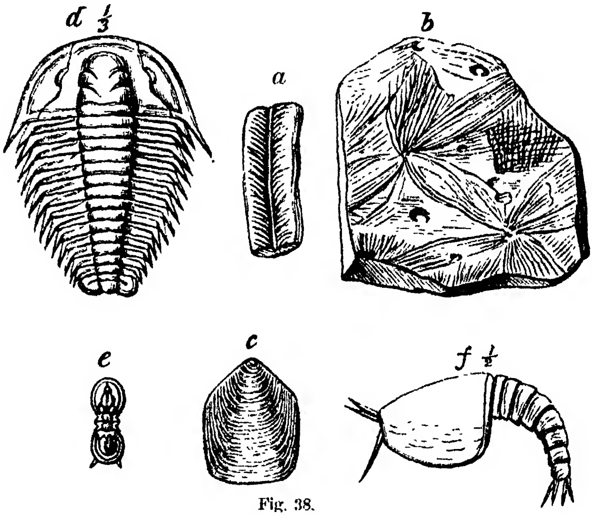


Fig. 38.

Lingula Flag Fossils.

a. Cruziana semplicata.
b. Dictyonema sociale.
c. Lingulella Davisii.
d. Olenus micrurus.
e. Agnostus pisiformis.
f. Hymenocaris vermicauda.

Fig. 38 *a*, *Cruziana semiplicata,* is supposed to have

Theca (*a sheath*) corrugata (*wrinkled*).
Protospongia (*first sponge*) fenestella (*little*
Cruziāna (*a proper name*) semiplicāta (*half folded*).

been part of a plant. *Dictyonema sociale* is believed to have been one of the polyzoan animals. *Lingulella Davisii* is a form very similar to the lower Cambrian *L. ferruginea.* The other three figures are those of crustacean animals; *Hymenocaris vermicauda* at once reminds us of the shrimps of our own seas, but is really a Phyllopod and not a Decapod Crustacean. *Olenus micrurus* and *Agnostus pisiformis* are Trilobites, an order of Crustacea we have already described.

The above-mentioned organisms are all found in the Lingula flags, but one of them, *Lingulella Davisii,* also occurs in the Tremadoc beds, together with other bivalve shells and Trilobites of the genera *Asaphus, Olenus,* and *Angelina.* See *Q. J. G. S.* xxix. p. 39.

Very few of the species which have been found in these Upper Cambrian beds continued to live during the deposition of the Arenig and Llandeilo series, the majority of the fossils being entirely different. There is therefore a break in the succession of life between the Tremadoc and Arenig groups, to be accounted for partly perhaps by the difference in their lithological character, and partly by the fact above noticed that there is an overlap of the Arenig and Llandeilo series beyond the area occupied by the Upper Cambrian rocks.

Here then most geologists seem now content to place the line of division between the Cambrian and

---

Dictyŏnēma (*net-thread*) sociāle (*social*).
Lingulella (*little Lingula*) Davisii (*of Davis*).
Hymenŏcăris (*membrane shrimp*) vermicauda (*worm-tail*).
Olĕnus (*a son of Jupiter*) micrūrus (*small tail*).
Agnostus (*unknown*) pisiformis (*pea-shaped*).

Silurian periods, although there is really no important break in the succession of strata until we reach the top of the so-called Lower Silurian, the Upper Cambrian of Professor Sedgwick.

Lower Silurian Period.

Wales and Shropshire.—If we ascend Nant Francon from Bangor, we find, after passing the Penrhyn slate-quarries, an immense series of rocks, consisting of dark grey or black slates interstratified in their higher parts with numerous massive beds of felstone and trappean ash These rocks are penetrated by large intrusive masses of greenstone and other igneous rocks, and are bent into many folds and broken by many faults.

They form the great mass of the Snowdon range, stretching throughout Caernarvonshire, and, sweeping round the Cambrian district of Harlech and Barmouth, they make the Merionethshire mountains known as the Arenigs, Aran, and Cader Idris. Plunging from these towards the east-south-east beneath some higher rocks, they rise again and form the Berwyn Mountains, and then undulate towards the south-east, forming the Breidden Hills and the Stiperstones, till the Cambrian rocks rise again from beneath them in the Longmynd of Church Stretton. In the Church Stretton valley they are broken through by a great fault, beyond which, after forming the base of the hill called Caer Caradoc, they dip steadily to the south-east, and soon become hidden by newer formations. From the country thus traversed, these rocks strike to the south-west through Cardigan-

shire, Caermarthenshire, and North Pembrokeshire, right out to St. David's Head, undulating frequently on the northern side of a line running by Builth, Llandovery, and Haverfordwest, but dipping on the south side of it at a very high angle beneath the superior rocks of Brecknock, Glamorgan, and South Pembroke.

These border counties of South Wales and England were formerly inhabited by the old British tribe of the Silures, and the country is now known to geologists under the name of Siluria, the name Cambria being retained especially for North Wales.

Subdivisions of Period.—The whole mass of these rocks can be subdivided into groups of beds more or less distinguishable in different districts by their lithological or stony characters, but still better by the peculiar fossils they contain.

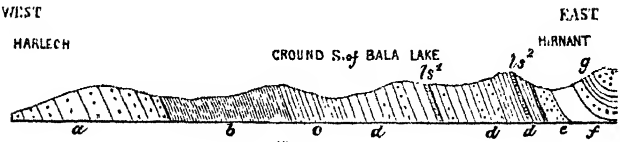


Fig. 39.

		Feet.
Base of Upper Silurian.	*g.* Denbighshire sandstones	9000
	f. Tarannon shales	500
Lower Silurian.	*e.* Lower Llandovery sandstone . .	300
	d. Bala or Caradoc beds	5700
	c. Llandeilo flags and A[illegible]ig beds . .	3300
Cambrian	*b* Lingula flags and Tre[illegible]doc Slates .	5000
	Barmouth and Harlech rocks . .	8000

The diagrammatic section in Fig. 39, reduced from the Geological Survey sections across the valley of Bala in Merionethshire, will give an idea of these groups. There are two locally occurring calcareous beds in the

Bala rocks, marked ls^1 the Bala limestone, and ls^2 the Hirnant limestone; they are only a few feet thick, but remarkable for the abundance of fossils they contain.

The Arenig Rocks.—These are not separated from the Llandeilo flags in the above section; they consist of dark flags and shales, first described by Professor Sedgwick in the Arenig mountains, and more lately worked out by Messrs. Salter and Hicks in South Wales, by whom they were shown to contain a fauna distinct from that in the beds above and below.

The Llandeilo Flags were first described by Sir R. I. Murchison, and were named from the small town of Llandeilo Fawr in South Wales. They comprise a series of micaceous flags and shales which are peculiarly rich in graptolites (see Fig. 40). In North Wales they contain very thick masses of felspathic lava and tuff, believed to have been the products of submarine volcanoes.

The Bala Beds are so called from the town of Bala in Merionethshire, near which they appear in their most typical and expanded form. The Caradoc sandstone of Sir R. I. Murchison is in part a sandy portion of these beds, but when first described other sandstones were confounded with it, so that the continued use of the word is likely to lead to mistake.

One of the sandstones thus confused with the Caradoc rocks has been separated under the name of the *Lower Llandovery* sandstone. It formed part of the Upper Bala group of Professor Sedgwick, and where present it immediately underlies the Upper Silurian beds.

Geographical Distribution.—The Lower Silurian rocks, thus characterised in the country where they were first examined and described, constitute a large part of the Lake country of Cumberland and Westmoreland (see p. 238), and of the hilly ground in the south of Scotland, between the English border and the valley of Edinburgh and Glasgow. They reappear in the north of Scotland, where, however, they have been almost entirely metamorphosed into the mica-schist and gneiss of which the Highlands are chiefly composed.

In Ireland they form nearly the whole eastern coast from Belfast Lough round to Dungarvan Bay in the County Waterford, and a large part of the interior both of Ulster and Leinster, in which latter province they have been penetrated by the largest mass of granite in the British Islands, and altered round the margin of the granite into mica-schist, etc. They soon become covered, however, towards the west by superior rocks, being only occasionally exposed in the rest of the country by the partial removal of these rocks till we come into Mayo and Donegal, where they again rise out in the form of gneiss and mica-schist, like those of the Scotch Highlands. The rocks of Donegal, indeed, doubtless stretch beneath the sea into the Highlands of Scotland, and those again into Norway.

In all these places, then, we have proof that during that period there was sea where now high and dry land is to be found. Whether the sea was continuous throughout these areas, or whether it was partially or entirely separated by intervening lands, we cannot tell.

There was certainly dry land somewhere in the neighbourhood of those districts, because it is only from the gradual waste of the dry land that the mud and the sand could be derived of which the rocks are composed.

Volcanic fires broke out in parts of these seas where the British Islands now are, and large accumulations of old lavas and ashes thus became interstratified with the other materials. Volcanic islands may even have been formed, though, if they were, they would be wasted and destroyed by the waves, and the materials strewed over the bed of the sea within the limits of the period, just as we know that during the existence of man volcanic islands have been both formed and destroyed sometimes within the space of a few months.

Life of the Period.—The following figures contain representations of a few of the fossils found in each of the groups of the typical Welsh district.

In Fig. 40 we have some of the fossils found in the next superior group. *Didymograpsus Murchisonii* and *Rastrites peregrinus* belong to the Graptolites, a kind of fossils which are very numerous in all the Lower Silurian rocks. They always show a number of little notches or indentations arranged on one or both sides of a narrow stem, and it is believed that these notches were the cells from which the individual heads of a compound animal protruded themselves. Professor Allman believes them to have belonged to the Sertularidæ. *Orthis alata* is an elegant little brachiopodous bivalve shell. *Trinucleus fimbriatus, Asaphus*

tyrannus, and *Ogygia Buchii*, are all species of dif-

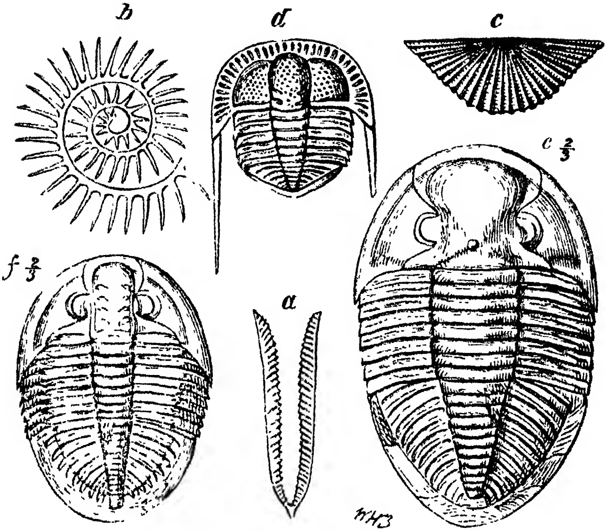


Fig 40.

Llandeilo Flag Fossils

a. Didymograpsus Murchisonii.
b. Rastrites peregrinus.
c. Orthis alata.
d. Trinucleus fimbriatus.
e. Asaphus tyrannus.
f. Ogygia Buchii.

ferent genera of the numerous order of Trilobites, as will be obvious by inspection of the figures.

Fig. 41 represents some of the fossils in the next superior group of rocks, four of which are species of

Didymŏgrapsus (*twin pen*) Murchisonii (*of Murchison*).
Rastrītes (*rake stone*) peregrīnus (*foreign*).
Orthis (*straight shell*) alāta (*winged*).
Trinŭclĕus (*three kernels*) fimbriatus (*fringed*).
Asăphus (*obscure*) tyrannus (*the tyrant, from its size*).
Ogȳgia (*Ogyges, a king of Thebes*) Buchii (*of Von Buch*).

Trilobites which are found in the Bala beds, *Illænus*

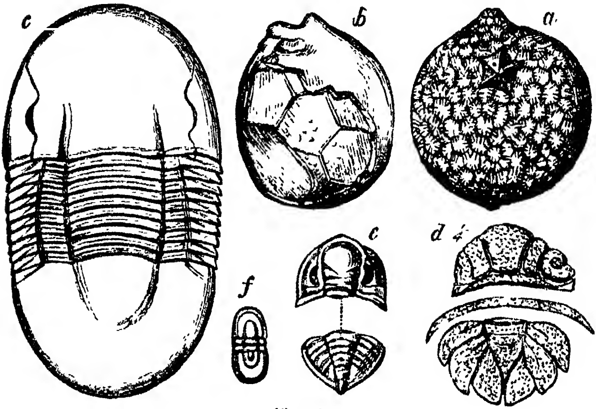


Fig 41

Bala (and Caradoc) Fossils.

a Echinosphærites aurantium.
b. Sphæronites Litchi.
c. Illænus Davisii.
d. Lichas Hibernicus.
e. Phacops apiculatus.
f. Agnostus trinodus.

Davisii, *Lichas Hibernicus*, *Phacops apiculatus*, and *Agnostus trinodus*.* They are given in order to show

Illænus (*squint-eye*) Davisii (*of Davis*).
Lichas (*an attendant of Hercules*) Hibernĭcus (*Irish*).
Phăcops (*lentil-eye*) apiculātus (*pointed*).
Agnostus (*unknown*) trinōdus (*three-jointed*).

* The recognised Latin word is trinodis. "Names, and their Origin," would make a curious subject of inquiry, whether they be names of men, of places, or of things. The difficulty of devising new names only becomes apparent when one is forced to try it; witness the ridiculous names for places in North America and in all our colonies. A short, well-sounding, appropriate name for a new object is as clever an achievement as a good proverb or a neat epigram, and is rare accordingly.

how numerous may be the variations on the same theme, as the musicians would say, or how the same general form and structure may be modified in its details. Or, if we take it another way, we may see from these and the following examples how a group of species which have small but decided differences among themselves, may be made into a genus with a common name, other groups being made into other genera, and then the genera all assembled into one order. Or if we take the examples given in these figures, and compare them in their order of succession, we may learn how one group of animals that lived at one time died out and were succeeded by others resembling them in some respects, but differing in others, and these again by yet more, with similar specific variations of the fundamental relationship.

There are also represented in Fig. 41 two globular bodies called *Sphæronites Litchi* and *Echinosphærites aurantium*. It will be seen that these are composed of several many-cornered plates, like the sea-urchins and star-fishes of our seas, and they obviously belonged to the same great class of Echinodermata (*thorny-skins*), though from the absence of arms, and spines, and other peculiarities in their structure, they may be grouped as a distinct order of that class, which was first done by Von Buch under the name Cystidea (*bladder-like*).

Numerous other fossils are found in these rocks, some beds being crowded with masses of shells, mostly Brachiopoda.

Sphæronites (*sphære-stone*) Litchi (*of Litch*).
Echinosphærĩtes (*thorny sphære*) aurantium (*an orange*).

UPPER SILURIAN PERIOD.

The Longmynd Island.—On turning back to Fig. 34, p. 218, it will be seen that while the Cambrian and Lower Silurian beds, *a*, *b*, *c*, are all parallel and conformable to each other, the Upper Silurian, *d*, rests unconformably on them at both extremities of the section. This unconformity was shown in Chapter XII. to be always proof of a great interval having occurred between the deposition of the two groups of beds, during which interval the lower one was elevated and denuded, and probably formed dry land before it was depressed again and covered by the upper groups.

Professor Edward Forbes, when working with Professor Ramsay and Mr. Aveline round the Longmynd in the year 1847, arrived at this conclusion from the nature of the fossils in the basal part of the Upper Silurian rocks. Many of the shells were univalves allied to those which now live only on coasts about the sea level, while in some places they were mingled with others that were more like deep-sea shells. Edward Forbes concluded, therefore, that the beds were not only deposited round the margin of land, but that in all probability they were deep-sea deposits round a high and steep island.—(*Quarterly Journal Geol. Soc.*, vol. iv. p. 298, where, however, the beds are called Caradoc sandstone, being then confounded with that formation.)

It is very interesting when we are thus able to restore, even in imagination, some of the outlines of the

ancient world. We must, however, recollect that although we may get good proof that there was an island in the old Silurian sea about the area where the Longmynd now stands, yet the present shape of the Longmynd gives us little or no indication of the shape of that old island. The whole country not only stood at a different level, but its rocks have been since tilted in various directions, and not only variously bent, but traversed by great fractures, so that one large district of rock has sunk far below or risen far above that with which it was then continuous. The present features of the ground, moreover, have been produced since all these disturbances, partly by the erosion of the sea when the country has happened to be at such a level as to allow the sea to flow over it, and partly by the erosion of the wind and rain and frost of the atmosphere when it has happened to be dry land, and we know that it has been both sea and dry land several times since the Silurian period.

Wales and Shropshire.—At page 226 it was said that the Lower Silurian rocks of Merioneth dipped to the east under some higher beds, and rose again into the Berwyn mountains. This eastern dip may be seen in Fig. 38, and the higher beds are there called the Tarannon shales and Denbighshire sandstones. These higher beds, and some others above them, spread over the county of Denbigh, wrap round the southern end of the Berwyns and other ridges to the south-east, till they pass round the southern termination of the Longmynd, and are affected by the great dislocation of the

Church Stretton Valley. From this point they strike to the south-west into South Wales in a continually narrowing band, disappearing altogether before they reach Caermarthen. Through all these districts they are composed chiefly of sandstones, flagstones, and slates, often with an aggregate thickness of several thousand feet, but with few natural divisions, and not many fossils.

To the south and south-east of the Church Stretton district, however, these rocks become separable into distinct groups of sandstones and shales, with persistent bands of limestone, which vary from 20 to 150 feet in thickness, and they are often crowded with assemblages of beautiful fossils, which are frequently most perfectly preserved. The picturesque ridge called Wenlock Edge, the beautiful hills round Ludlow and Aymestry, the Abberley and Malvern hills that rise with such elegant outlines from the rich plains of Salop, Worcester, and Hereford, the singular amphitheatre of Woolhope, and its continuation into May Hill, are all localities where the Upper Silurian rocks, with their bands of limestone, are admirably shown, and where the geologist may at any moment refresh his eye, should it weary of rocks and fossils, with views of the lovely scenery about him. The hills between Usk and the end of the wonderful coalfield of South Wales are likewise good places for their study, as well as those which run from Dudley to Sedgley, and rise again near Walsall, in the still more wonderful though much smaller coalfield of South Staffordshire.

All these places, except the last mentioned, are in the typical district of the old Silures, whose territory lay chiefly between the Severn and the Towy.

Subdivisions of Period.—These rocks exhibit in this district a threefold division into groups, which have received from the three places where they are best seen the names of—1. Llandovery rocks; 2. Wenlock rocks; 3. Ludlow rocks. Fig. 42 is a condensed section across Wenlock Edge in Shropshire, where, however, the Llandovery rocks are very thin and not well shown.

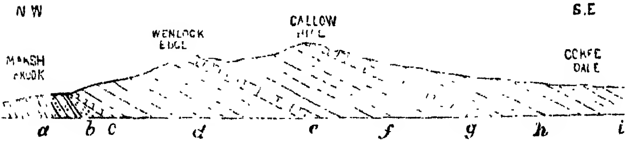


Fig. 42.

Section across Wenlock edge, horizontal distance about four miles.

			Feet.
		i. Tilestones, base of Old Red Sandstone.	
Upper Silurian.	Ludlow rocks.	*h.* Upper Ludlow—Grey and brown shale and sandstone	900
		g. Concretionary limestone (Aymestry) . .	150
		f. Lower Ludlow—Grey and brown calcareous sandy shale	900
	Wenlock rocks.	*e.* Grey nodulary concretionary limestone (Wenlock and Dudley)	150
		d. Grey and brown sandy shale, often concretionary (Wenlock shale)	1400
		c. Argillaceous nodular limestone (Woolhope and Burr)	50
	Llandovery	*b.* Brown sandstone and conglomerate.	
	Lower Silurian	*a.* Brown sandstone (Caradoc or Lower Llandovery).	

It will of course be recollected that the lithological (*stony*) characters of the rocks are mere local accidents, and that not only do the beds of limestone disappear in every direction, but that all the other beds are mere

partial cakes of deposit, and that they may be replaced by others of a more or less dissimilar character. (*See* pp. 196 and 210.)

The Silurian series, as before mentioned, occurs again in Westmoreland and Cumberland, where they are capable of division as follows:—

Kendal flags	=	Ludlow rocks.
Ireleth slates	=	Wenlock rocks.
Coniston grits	=	Llandovery beds.
Coniston limestone	=	Bala beds.
Slates and porphyry	=	Llandeilo flags.
Skiddaw slates	=	Arenig rocks.

Upper Silurian rocks are at present known in only three localities in Scotland; but in Ireland they are largely exposed in Galway and in Kerry, where they appear to represent the Wenlock and Ludlow groups.

Life of the Period.—The fossils of the Llandovery beds are, some of them, peculiar, especially some species of a Brachiopodous bivalve called *Pentamerus*. The most striking fossils, however, are found in the limestones of the Wenlock and Ludlow groups, and the following woodcuts show figures of some of these.

Calymene Blumenbachii and *Phacops caudatus* are two other species of Trilobites. Of the two Echinodermata, the one, *Pseudocrinites quadrifasciatus*, belongs to the Cystidea, of which we had examples

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Pentamerus (five parts, from its internal structure).
Calȳmĕne (*concealed*) Blumenbachii (of *Blumenbach*).
Phăcops (*lentil-eye*) caudatus (*tailed*).
Pseudocrinītes (*false stone-lily*) quadrifasciatus (4-*banded*).

before; the other called *Periechocrinus moniliformis*, was a true stone-lily, a kind of starfish, growing on a jointed stem with its body bent into a cup and its

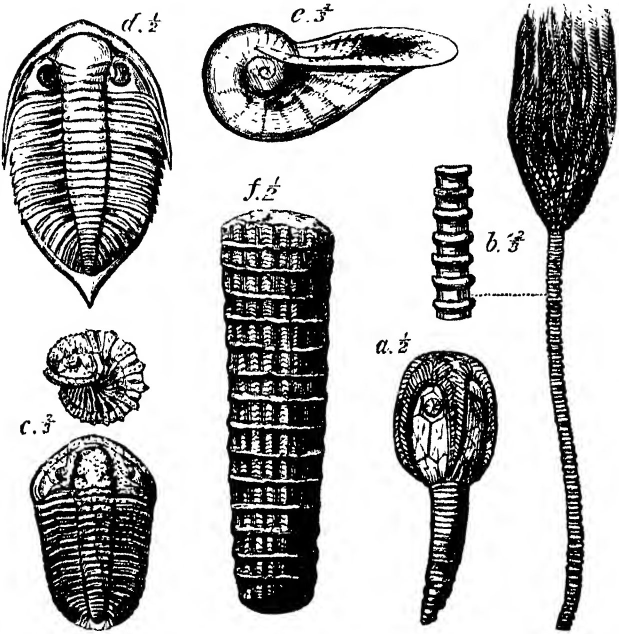

Fig 43.
Wenlock Fossils.

a. Pseudocrinites quadrifasciatus.
b. Periechocrinus moniliformis.
c. Calymene Blumenbachii.
d Phacops caudatus.
e. Bellerophon dilatatus.
f. Orthoceras annulatum.

fingers divided into numerous jointed strings and filaments. This class of animals became excessively

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Perĭēchocrinus (*clasping lily*) monīlĭformis (*necklace-like*).

numerous in subsequent periods, though it is now almost entirely extinct.

Bellerophon dilatatus was a univalve shell, believed to have belonged to one of the Oceanic Pteropods or Heteropods, while *Orthoceras annulatum* was one of the Cephalopods, a class of animals to which the cuttle-fish belongs—the *Orthoceras* being a chambered shell like a pearly nautilus, but as if unrolled and pulled straight.

Besides these, multitudes of elegantly marked bivalve shells are found in these rocks, chiefly belonging to the class Brachiopoda, and many kinds of Corals, some of which resemble in external appearance the Corals of the present tropical seas, but some differ from them in the details of their internal structure, so as to form a separate order called Rugosa, all of which are now extinct.

In the following group of fossils we have a few species represented, which are all, except the first, characteristic of the Ludlow rocks—that is to say, they are either entirely confined to them, or occur much more abundantly in them than elsewhere.

Graptolithus is almost the only genus of Graptolite found in the Upper Silurian rocks; two other genera occur in the Wenlock, but do not pass up into the Ludlow beds. Graptolithus has cells only on one side; most of the double Graptolites, or those which have branching stems, or have cells on each side of the stem, appear to have died out and become extinct, together

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Bellerŏphon (*a mythic personage*) dilatatus (*extended*).
Orthocĕras (*straight-horn*) annúlatum (*ringed*).
Graptolithus (*pen-stone*) priodon (*saw-tooth*).

with many kinds of Trilobites, before the Upper Silurian period commenced. At its close, the one or two single Graptolites which still survived also disappeared from the earth for ever as living beings.

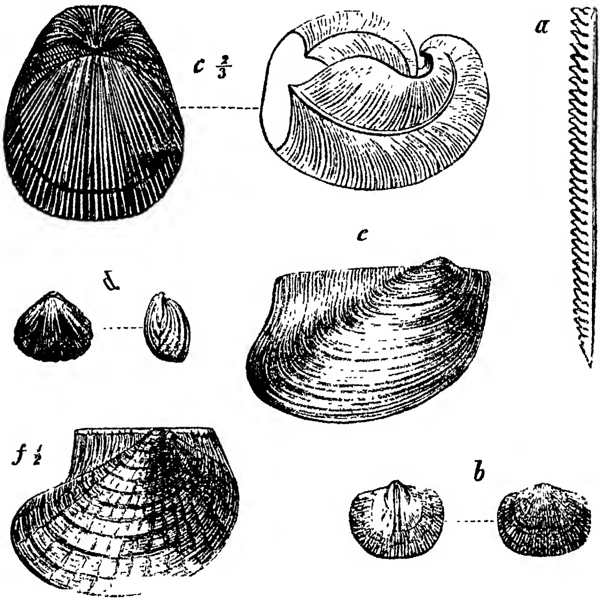

Fig. 44.
Ludlow Fossils.

a. Graptolithus priodon.	d. Rhynchonella nucula.
b. Orthis lunata.	e. Pterinea retroflexa.
c. Pentamerus Knightii	f. Avicula Danbyi.

This early disappearance of types of animals forms a remarkable contrast to the persistence of some other types, such as the genus *Lingula* which, through the form

Lingulella (p. 223), seems to have been always represented from the Cambrian period down to the present hour, when there are said to be sixteen species living.* *Rhynchonella* again dates from Lower Silurian times, and is found in all subsequent marine formations.

The other figures all represent bivalve shells, the three first Brachiopoda, and the two last Conchifera. *Orthis lunata* and *Rhynchonella nucula* are rather common fossils throughout the Ludlow rocks, while *Pentamerus Knightii* occurs in some parts of the Aymestry limestone in such abundance as to compose the entire mass of the rock. This is a curious shell, of which the large or ventral valve is separated into two parts by an internal shelly plate, and the smaller or dorsal valve into three parts by two similar plates, one on each side of that in the ventral valve (*see Fig.* 44 *c, in which the ventral plates and one of the dorsal are shown*). Almost all the Brachiopoda have some curious internal shelly processes (*see* p. 267), but none so peculiar as this in Pentamerus, in which it is difficult to understand what could have become of the animal's body. Another species, *P. galeatus*, is common in Wenlock rocks.

Of the two Conchifers, or ordinary bivalves, the *Avicula Danbyi* belongs to a genus which has come down to our own day; there are twenty living species

Orthis (*straight shell*) lunāta (*half-moon-shaped*).
Rhynchonella (*little beak*) nucŭla (*a little nut*).
Pentamĕrus (*five parts*) Knightii (*of Knight*).
Avicŭla (*little bird*) Danbȳi (*of Danby*).

* See "Woodward's Manual of the Mollusca," a most valuable and useful book.

of it, and not less than 300 extinct ones are known in different rocks. *Pterinæa retroflexa* belongs to a sub-genus of Avicula made to include certain Palæozoic species, which, in certain characters resemble each other, and differ from other species of Avicula.

Besides the above there are many other fossils in the Ludlow rocks; several star-fish, for instance, very similar in general form to some living ones, and several genera allied to Orthoceras, but differing from it in having curious bulging and irregular outlines instead of the straight regularly tapering shell.

The remains of true fish also occur in the Ludlow rocks, being their earliest appearance yet known. These remains consist of the teeth and shagreen of a shark-like fish *Onchus*, and also some others of very strange and peculiar forms, called *Cephalaspis*, *Pteraspis*, and *Auchenaspis;* and these are found also in the sandstones ("*Tilestone*") above the proper Ludlow rocks, extending up into some red rocks that have been hitherto called Old Red Sandstone. The base of these red rocks is shown in Fig. 42, p. 237, and a thickness of several thousand feet of them appears over the Ludlow rocks in Siluria, as well as in Scotland and Ireland. There are also found in the Upper Ludlow rocks fragments of large Crustacean animals, which are more like lobsters in external form than Trilobites are, but still differing from lobsters in important par-

Pterinæa (*little wing*) retroflexa (*bent back*).
Onchus (*a hook*). Cephalaspis (*head-shield*).
Pteraspis (*wing-shield*). Auchenaspis (*neck-shield*).

ticulars. They are called *Pterygotus* and *Eurypterus*, and become especially large and abundant in the Tilestones and the red beds above. Fragments have been found that must have belonged to a *Pterygotus* six or seven feet long. The fossils were called Seraphim by the Scotch quarrymen near Dundee, where the largest specimens have been discovered in the Lower Old Red Sandstone. (See Mr. Woodward's monograph on the *Merostomata*, published by the Palæontographical Society.)

Pterygōtus (*winged*). Euryptĕrus (*broad-winged*).

CHAPTER XVII.

The Three later Palæozoic Periods, or those of the Upper Palæozoic Rocks.

DEVONIAN PERIOD.

Old Red Sandstone.—It was stated towards the end of the last chapter that in the typical Silurian district there was a great mass of red sandstones, the lower portion of which seemed closely connected with the Silurian rocks below, and the upper portion to belong to the rocks above it, and that this great series of red deposits had been all grouped together as the Old Red Sandstone.

In parts of South Wales this Old Red Sandstone has an aggregate thickness of at least 10,000 feet. It consists of many beds of variously coloured sandstones, the predominant hue being red or purple, interstratified with beds of red or mottled marl and clay, and beds of sandy and clayey limestone, locally called *cornstone*, from its disintegrating in grains or corns, together with some thick conglomerates.

Fig. 45 shows the relations of the rocks in a part of South Wales near Llandeilo fawr,* where the Silu-

* In pronouncing Welsh words a single f is like the English v ; when it is to be sounded like f it is doubled, thus, ff. The

rian rocks and the lower part of the red series are quite vertical, while the upper red rocks dip gently to the south beneath the great coalfield of South Wales.

It is impossible in Siluria to separate this great series into distinct groups. In Ireland and Scotland,

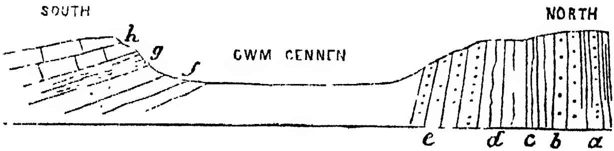

Fig. 45.

Section across Cwm Cennen, three or four miles south-west of Llandeilo fawr. Length of section about three miles.

			Feet.
Carboniferous	h.	Carboniferous limestone	500
	g.	Lower limestone shale	100
Old Red Sandstone.	f.	Red and yellow sandstones	80
		space of nearly a mile in which no rock is visible.	
	e.	Red Sandstones, shales, and cornstones	1200
Upper Silurian	d.	Laminated red and grey beds	200
	c.	Laminated grey beds (Tilestones)	450
	b.	White and grey sandstone (fossiliferous)	350
	a	Laminated sandstone and shales (fossiliferous)	500

however, there are districts where a similar great mass of red sandstone occurs above the Silurian and beneath the Carboniferous rocks, but which are separable in Ireland into two groups by a wide and distinct unconformity of the upper portion on the lower, and in Scotland into three groups by two unconformities. In Ireland the lower part has been called the Dingle Beds, from the name of a town which stands on them. In

double Ll has a peculiar sound that no "*Sassenach*" mouth can properly pronounce.

Scotland the divisions are at present called the Lower, Middle, and Upper Old Red Sandstone; the Lower passes down conformably into the Silurian rocks, and contains the Silurian genera *Cephalaspis*, *Pteraspis*, and *Pterygotus*; the Middle are often grey in colour, and contain fishes of the genera *Pterichthys*, *Coccosteus*, etc., as well as land-plants; in the Upper group is found the Carboniferous fish *Holoptychius*.

In all three countries—namely in Scotland, in Ireland, and in South Wales—the uppermost portion of the red series passes conformably upwards into the Carboniferous system, and it contains the remains of plants either identical with, or closely allied to, those of the Carboniferous rocks, and an assemblage of fossil fish, some of which are peculiar to it, while others are also found in the Carboniferous rocks.

Rocks of Devon and Cornwall.—Now the question may well be asked here, What have all these descriptions to do with the Devonian Period? We will endeavour to answer this question as briefly as possible.

In Devonshire and Cornwall there is a great series of slates with bands of limestone, which series is covered by a thick deposit of culm measures which are undoubtedly of Carboniferous age. The slates and limestones contain fossils, some of which are found elsewhere in the Carboniferous rocks, while others are not, but are peculiar to the rocks of Devon and Cornwall so far as England is concerned. Some of these fossils, especially some Trilobites, are more like Silurian forms than those elsewhere found in Carboniferous rocks. It

was therefore shrewdly guessed by Mr. Lonsdale, when he examined the fossils collected by Professor Sedgwick and Sir R. I. Murchison, and saw the maps and sections which they had constructed, that these rocks held an intermediate place between the Upper Silurian and true Carboniferous formations. If so, then they held the same place as the Old Red Sandstone did, and therefore were homotaxial and perhaps contemporaneous with it.

There is of course no reason why the same formation should not consist chiefly of sandstone in one district, and of slate and limestone in another—the one probably containing fossils derived from the land, and the other those of the open sea. To this period, therefore, which intervened between the Silurian and Carboniferous systems, the name Devonian was given, and has been rather widely adopted as a short well-sounding term derived from one of the supposed typical districts; but to what extent the rocks of Devon and the Old Red Sandstone are contemporaneous has not yet been clearly ascertained. The late author of this book, however, considered that the so-called Upper Devonian or Marwood sandstone of North Devon was above the topmost beds of the true Old Red Sandstone, and that it belonged to the Carboniferous series. This he thought was proved by the structure of the south of Ireland as compared with North Devon.

In the County Waterford we have the true upper Old Red Sandstone in its ordinary form, as it occurs just beneath the Carboniferous limestone in South Wales, with a thin group of black shales between it

and the base of the Carboniferous limestone, exactly as in the southern end of the section Fig. 45. As we trace these rocks to the west-south-west from Waterford into the County Cork, both the Old Red Sandstone and the black shales above it get thicker and thicker till each are several thousand feet thick. Both become affected also by slaty cleavage, so that all their more fine-grained argillaceous beds become true clay-slate.

The upper part of this cleaved Old Red Sandstone continues to show the same fragments of plants and other terrestrial fossils as before, and the black shales or slates the same marine shells as before; but there are beds of grey and greenish grit which make their appearance in the lower part of the black shales, and contain some large bivalve shells (*Cucullæa*, etc.) and other fossils not known in any other beds, mingled with common Carboniferous fossils. These Grits, which eventually become about 3000 feet thick, are called Coomhola Grits in Ireland, and the black shales, when they thus thicken out and become cleaved, have been called the Carboniferous Slate by Sir R. Griffith.

There is no doubt that the Coomhola Grits are identical with the Marwood sandstones of North Devon, both lithologically and in their fossil contents, and the Carboniferous slate is identical with the so-called Upper Devonian black slate which runs just north of Barnstaple in North Devon; but whether these beds should be taken as the top of the Devonian or as the

base of the Carboniferous series is another question: Mr. Jukes inclined to the latter classification, and in fact did not believe that any of the rocks of Devon were equivalent to the true Old Red Sandstone, and doubted, therefore, whether the name Devonian could still be applied to the period. Most geologists, however, believe that these rocks correspond with some part of the Old Red Sandstone, and the name Devonian is therefore retained for the whole period.

The red rocks which occur on the north side of Baggy Point, in Devon, and which strike thence eastward in a straight line into the country as far as Exmoor, are apparently identical with the top of the Old Red Sandstone in County Cork. The exact equivalents of the rocks about Ilfracombe, and the shales and limestones running from Newtown Bushel to Plymouth, cannot yet be regarded as satisfactorily determined. The Lynton beds, Mr. Etheridge supposes to be on the horizon of part of the Dingle beds and the Lower Old Red Sandstone of England and Scotland, but Mr. Jukes would place these also with the Upper Old Red Series.

Devonian Fossils.—The following group exhibits some fossils characteristic of the Devonshire rocks:—

Stromatopora placenta, Fig. 46 *a*, is a curious sponge-like form, the affinities of which are not yet determined. Fig. 46 *b* is the tail of a trilobite called *Bron-*

Strŏmatopŏra (*porous strata*) placenta (*a cake*).
Brontéus (*one of the Cyclopes*) flabellifer (*fan-tailed*).

teus flabellifer. Stringocephalus Burtini is a Brachiopod. *Calceola sandalina* was formerly referred to the same group, but is now known to be one of the *Rugose*

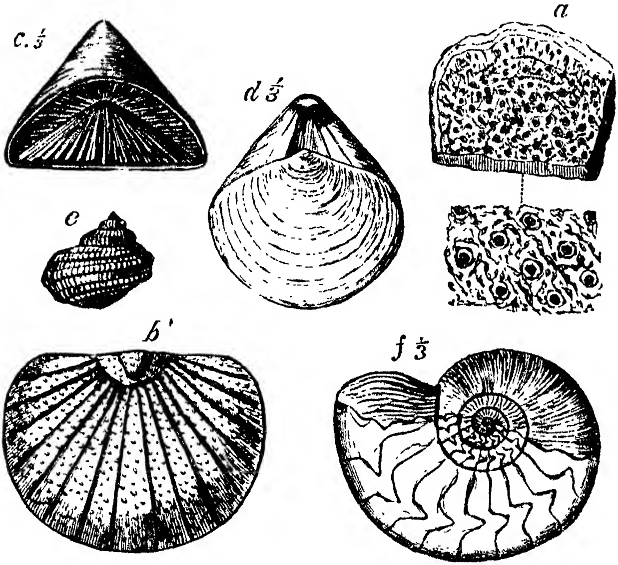

Fig. 46.
Devonian Fossils.

a. Stromatopora placenta.
b. Bronteus flabellifer.
c. Calceola sandalina.
d. Stringocephalus Burtini.
e. Pleurotomaria aspera.
f. Clymenia striata.

Corals belonging to the Family *Cyathophyllidæ. Pleuro-*

Stringocĕphălus (*owl-head*) Burtini (*of Burtin*).
Calcĕŏla (*a slipper*) sandălina (*like a sandal*).
Pleurotomāria (*side slit*) aspĕra (*rough*).
Clymēnia (*a sea nymph*) striata (*striated*).

tomaria aspera is a Gasteropod similar in shape to a Turbo, but having a deep slit in the side of its mouth. *Clymenia striata* is a Cephalopod related to the pearly Nautilus.

A careful perusal hereafter of the papers that have been written on the Devonian system will be instructive to the student, as showing the nature of the researches which geologists undertake, and the labour and pains that have to be incurred before the different groups of rock can be arranged in their proper order, or the history of their formation be truly and regularly told. In this case Devon and Cornwall, Wales, Scotland, and Ireland, have each to be minutely examined, and parts of their structure compared with each other both by the same and by different observers. Their fossils have similarly to be collected, figured, described, and compared; and all this has to be done in some cases again and again through a series of years, and the first conclusions corrected or supported by subsequent re-examinations.

Carboniferous Period.

The Carboniferous rocks occupy large areas in England, Ireland, and Scotland, and present several distinct types, which will be best understood from descriptions of the districts in which they occur.

South Wales.—In Fig. 45 we have a section, the southern end of which brings us just to the northern edge of the South Welsh coalfield, showing how the Old Red Sandstone there dips beneath some black shale and limestone, which are called Carboniferous rocks. The following Figure 47 will enable us to continue that section into the coalfield itself, and show the rocks which lie above the limestone.

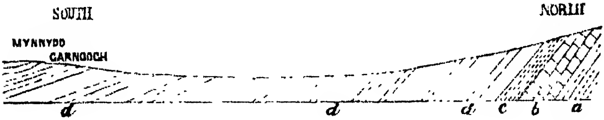

Fig. 47.

		Feet.
d.	Coal-measures, with 50 seams of coal varying from 6 inches to 6 feet	9600
c.	Farewell rock (Millstone grit of Derbyshire)	400
b.	Carboniferous limestone, including the black shale	700
a.	Old Red Sandstone.	

Along all the northern edge of the great coalfield of South Wales, thick beds of pale grey limestone, with an aggregate thickness of many hundred feet, rise to the surface, and often form crags and cliffs fronting the north, while they dip gently to the south, and sink in that direction beneath the beds in which the coal-

seams lie. These beds form a vast series of interstratified sandstones and clays of various kinds, colours, and qualities, making up a total thickness certainly of 7000 and possibly of even 12,000 feet. Sandstone predominates in the lower parts, just above the limestone, making a sub-group which the coal-miners call the "Farewell rock," because, whenever they sink a shaft down to it they know that they may bid farewell to the coal. The beds of coal are numerous above these Farewell sandstones throughout the rest of the series, with the exception of another barren band of sandstones called the Pennant grits, about its middle part.

The search for these beds of coal gives us exact information as to the nature and thickness of this group of rocks, as may easily be understood by looking at the section, Fig. 47, and supposing a shaft to be sunk in the first instance, in the higher beds about Mynnydd * Carngoch through the six highest beds of coal indicated by the lines there. Then suppose these coals to be worked on their rise up to their outcrop, and a second vertical shaft sunk farther north, under the "o" of goch for instance, down to the three next beds, and these in like manner to be worked out to their outcrop, and the process repeated, each pit sunk from the outcrop of one known bed to the deep part of the bed below it; it is obvious that we shall ultimately get a knowledge of the structure of all the beds below

* In Welsh *dd* is pronounced like *th* in the English word *the*, and Mynnydd is pronounced as if spelt "Munnyth;" it means "the mountain," and Carngoch means the "red cairn."

Mynnydd Carngoch, and the depth that the lower beds would reach to there. This could be done by continuing the inclined lines in the section, Fig. 47, below the horizontal line, and if the figure were to be accurately drawn to scale, the depth, even of the Limestone *b*, and the Old Red Sandstone *a*, could be ascertained.

In Fig. 48 we have a sketch section across a smaller coal-measure district, in which the beds have also been bent into a basin shape.

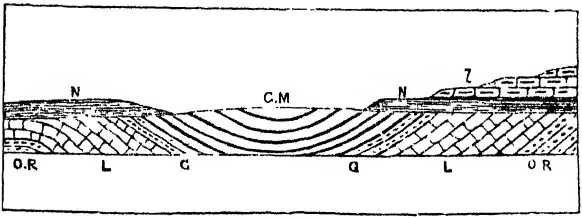

Fig. 48.

Section of Bristol coalfield, taken from Mr. Hull's "Coalfields of Great Britain."

L. Lias and Oolites.
N. Upper Trias.
C M. Coal-measures.
G. Millstone Grit.
L. Carboniferous Limestone
O R. Old Red Sandstone.

This represents the structure of the Bristol coalfield, in which large parts of the outcropping edges of the beds are unconformably covered by newer deposits, which will be described in a future chapter.

The Pennine Chain.—In Derbyshire, and in the counties on each side of it, we have another district showing a good type of the Carboniferous series. Here, however, instead of lying in a basin with the Coal-measures in the centre, the Carboniferous limestone

occupies the centre in the form of a broad gently sloping anticlinal arch, the axis of which runs north and south, while its sides dip east and west respectively; the Carboniferous Limestone dipping under the Millstone Grit, and that under the Coal-measures in each direction.

The western flank of the anticlinal is more irregular than the eastern, of which Fig. 49 may be taken as a rough section at one part.

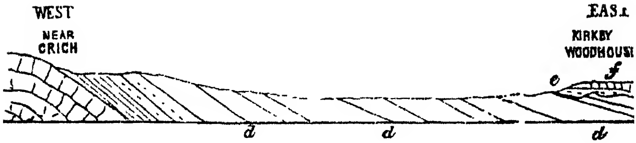

Fig. 49

Section across part of the Derbyshire coalfield, omitting the faults and the flexures.

Permian Rocks.	*f.* Magnesian Limestone	
	e Rothetodtliegende (occasional).	Feet.
Carboniferous Rocks.	*d.* Coal-measures	3700
	c. Millstone Grit	350
	b. Yoredale Rocks	250
	a. Carboniferous Limestone	800

The Carboniferous limestone is nearly horizontal in the centre of the Derbyshire district, forming ground of which the general level is about 600 or 800 feet above the sea. The numerous brooks and rivers have cut deep valleys into it, forming the beautiful Dales of Derbyshire, which, in the limestone districts, are bounded chiefly by vertical cliffs* of pale-grey lime-

* A long line of cliffs is called a "scaur," a single bold one is called a "torr," while a round-topped hill is a "lowe;" names with which every Derbyshire tourist must be familiar.

stone. These dales, excavated in the inclined beds, show a thickness of limestone equal to 800 or 1000 feet; but they nowhere cut so deep, nor does the limestone anywhere rise so steeply, as to show its bottom beds, or enable us to determine whether there is any Old Red Sandstone below it, or whether it rests unconformably on some older rock.

Two very remarkable bands of igneous rock are interstratified with the limestone in Derbyshire, and well shown in many of the dales or along the hill-sides. This rock is a kind of basalt, but is called by the miners "toadstone," being often coloured and spotted like a toad's back;* it is often associated with soft clays, mottled green and red in various shades. These bands are old submarine lava streams poured out on the bed of the sea at intervals during the formation of the limestone, each band of toadstone being formed of several flows of this old lava, while the clays are the decomposed "ash" that was ejected occasionally during the outpouring of the lavas.

The limestone part of the district is everywhere surrounded by a broad open dale formed by the excavation of the soft black shales and sandstones which lie over the limestone, and are known by the name of the Yoredale rocks. This valley has the central limestone hills on one side, but on the other is everywhere, except towards the south, girdled by bold sweeping

* Or else derived from the German word "Todtstein" (*dead stone*), because the lead veins "die out" on approaching the greenstone, and were supposed not to occur beneath it.

hills of Millstone Grit. These hard thick sandstones often form lines of dark beetling crags along the summits of the escarpments which look down on the valleys and face the central hills of limestone; while in the other direction they form broad, undulating, heathery moorlands, till they gradually sink down, towards the east and west, into the busy, but black and smoky, haunts of the coalfields.

Yorkshire and Durham.—The anticlinal ridge of Carboniferous rocks which rises in Derbyshire is continued northwards into Yorkshire and Durham. It is, however, in some places irregular, so that the coalfields on its flanks are separated from each other by cross-flexures, and towards the north its western flank is broken down by great faults and dislocations. There is, moreover, a remarkable change to be observed in the constitution of the rocks. The Upper Limestone shale which forms Mam Torr (or the Shivering Mountain), just north of Castleton, spreads to the northward of that town, over the crest of the anticlinal, entirely concealing the limestone, and is itself covered by the Millstone Grit, which forms a series of wild moors in Kinder Scout, the Featherbed Moss, and other high and barren districts, which stretch thence for miles and miles towards the north.

This long, gently sloping table-land, forming moors and mosses, fells and forests of many names, rarely sinking so low as a thousand, and often exceeding two thousand feet in height above the sea, is sometimes spoken of as the Pennine Chain of England. The

rivers that run down its eastern slope have cut deep winding valleys into the rocks below, and expose the beds so clearly and frequently that the miners have given names to their different groups by which they familiarly distinguish them. Airedale, Wharfedale, Wensleydale, Swaledale, Teesdale, Weardale, are some of the best known of these valleys.

In all this district the Carboniferous limestone becomes more and more split up by interstratified shales and sandstones as we proceed towards the north, and in Yorkshire the group goes under the name of the Great Scaur Limestone, while limestones make their appearance in beds that are probably the same as the Yoredale rocks of Derbyshire. Thin beds of coal likewise come in with shales and sandstones in the Millstone Grit, and the upper part of this complex series dips towards the east, under the Newcastle coal-field, where it is covered by upwards of 2000 feet of Coal-measures without any distinct top being reached.

A section drawn across the country, from the valley of the Eden to the mouth of the Tyne, would exhibit the following series of rocks :—

	Feet.
4. Coal-measures	more than 2000
3. Millstone Grit	414
2. Yoredale series	540
1. Scaur Limestone group . . .	more than 1120

In the northern part of Northumberland the limestones become still thinner and fewer, and in Berwickshire good beds of coal are worked near the base of the Scaur Limestone group.

Scotland.—In the Scotch coalfields between Edinburgh and Glasgow, the whole series is a Coal-bearing one, resting directly on the Old Red Sandstone, with a few comparatively thin bands of limestone in the lower part of the series.

Mr. Geikie gives the following condensed classification of the carboniferous series of Scotland :

	Feet.
4. Upper or Flat Coal series of Mid-Lothian . .	1800
3. Moor Rock or Rosslyn Sandstone . . .	1500
2. Carboniferous Limestone series, consisting of shales sandstones, limestone, and coals . .	1100
1. Calciferous Sandstone (fresh water) ; thickness considerable.	

Ireland.—In Ireland the Carboniferous formation occupies a greater comparative area of the surface than in any other country, the Carboniferous Limestone being the surface rock right across the island, from Dublin Bay to Galway Bay, and over a large part of the interior both north and south of that line. This limestone, with a total maximum thickness of about 3000 feet, was, doubtless, at one time covered by the Coal-measures, with, perhaps, good beds of coal in their upper parts. Patches of these Coal-measures are, indeed, still left here and there, forming hills that rise sometimes several hundred feet above the limestone plain. This is more especially the case where the beds have been bent into a basin shape, so that the upper beds dip beneath the present surface of the ground. Fig. 50 is a diagrammatic section across one of these little basins near Killenaule, in county Tipperary.

In the north of Ireland great beds of sandstone and shale appear in the lower part of the Coal-measures, and the limestone is divided into an Upper and Lower group by a series of sandstones and shales called the Calp, somewhat in the same way as in Yorkshire. In

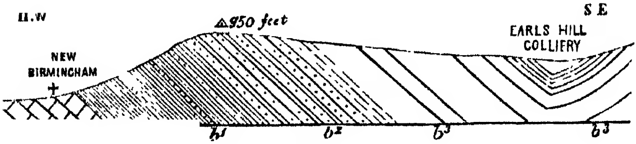

Fig. 50.

Section of Slievardagh Coalfield, Tipperary.

Length of section about 1½ mile.

		Feet.
Coal-measures.	b^3 Black shales and grey grits, with small beds of coal	1300
	b^2 Flagstone series, grey sandy flags and black shales .	700
	b^1 Black shales, with occasional thin bands of grit .	800
	a. Carboniferous limestone, upper beds.	

the south of Ireland it has been already stated that the Lower Limestone shale which lies beneath the limestone suddenly swells out to an enormous thickness, as much as 5000 or 6000 feet. The late author saw reason to suspect that this may possibly have been simultaneous with a thinning of the limestone above, and that part of the Carboniferous Slate may really be contemporaneous with part of the limestone. Mud and sand may easily be supposed to be deposited in one part of a sea, while limestone is forming in another. Some of the animals that lived in that sea may have spread through both parts, while others may have been restricted to the one that suited them best.

Life of the Period.—The fossils found in the Carboniferous rocks consist of numerous plants as well as

animals, the plants being usually found in the shales or sandstones, while the animals are most abundant in the limestones, though they have occasionally left numerous impressions in the sandstones, or are preserved in the clays.

Among the plants we find the impressions of many varieties of the leaves of ferns that may possibly have belonged to tree-ferns, while there are also large stems of trees showing the structure of coniferous wood. In Fig. 51 *b* we have a specimen of a piece of fern leaf called *Alethopteris lonchitica.* In Fig. 51 *a* is represented the end of a jointed fluted stem which is very common. It is called *Calamites cannæformis*, and is supposed to have been allied to the Equisetaceæ (*Horse-tails*) of the present day. Fig. 51 *d* represents part of a plant called *Lepidodendron elegans*, which botanists think must have been one of the Lycopodiaceæ (*Wolf's foot kind*), to which the club mosses of our mountains belong. Trees of *Lepidodendron*, forty or fifty feet long, however, have been discovered, and multitudes of their seed cones, like larch cones in shape. The other two figures, 51 *c* and *e*, were in reality parts of one plant, although going by different names. The genus *Sigillaria* was the upright stem of the plant, and *Stigmaria* was the root of it, from which

Alethoptĕris (*true fern*) lonchītica (*lonchitis-like*).
Calămītes (*reed-stone*) cannæformis (*cane-shaped*).
Lepidodendron (*scale tree*) elĕgans (*graceful*).
Sigillāria (*seal stamped*) rēniformis (*kidney-shaped*).
Stigmāria (*pitted-plant*) ficoides (*fig-like*).

numberless rootlets proceeded on all sides into the mud in which it grew. There are about forty species of

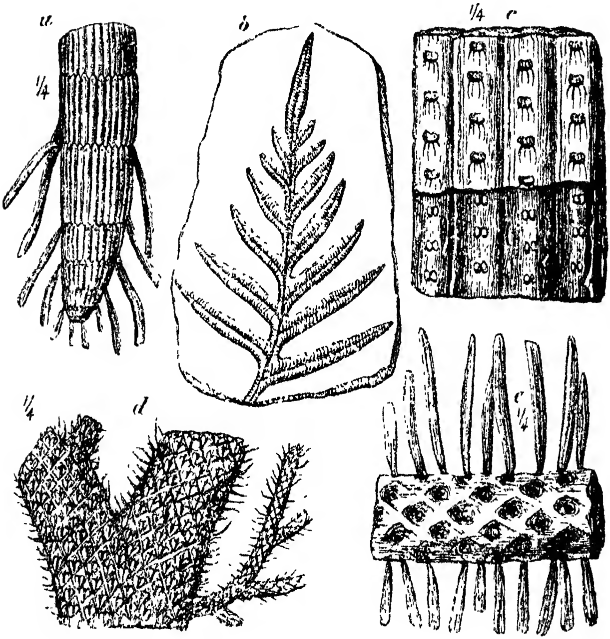

Fig 51

Carboniferous Plants

a. Calamites cannæformis. *c.* Sigillaria reniformis.
b. Alethopteris lonchitica. *d* Lepidodendron elegans.
e Stigmaria ficoides.

Sigillaria, of which *reniformis* is the one figured, and several pieces of Stigmaria, besides *ficoides*.

These plants certainly contributed largely to the

formation of most beds of coal in the Carboniferous rocks, and from the abundance of Stigmaria usually found beneath each bed of coal, it appears that the Sigillaria must have grown on the spot, and the coal must have been principally formed of their decay. The stratification of coal-beds, and that of the shaly partings and beds between them, is in favour of their having been accumulated, to a certain extent, under water, in which case these Sigillaria must have been aquatic, or, at any rate, marsh plants.[*] The mangrove swamps of tropical countries perhaps make the nearest approach in modern times to the conditions under which the coal-beds were deposited.

Beds of coal in the Coal-measures are found of all thicknesses, from half-an-inch up to three feet, but they rarely exceed that, thicker seams of coal being formed by several beds resting directly one upon the other, with only very thin partings, or none at all, of the intermediate clays or sands which elsewhere separate them. In part of the South Staffordshire coalfield thirteen such beds are associated into one great compound seam thirty feet thick, long known under the name of the Thick or Tenyard coal. This, however, is, within the space of five miles in one direction, split up by intermediate beds of sand and shale into eight or nine separate seams, the whole group of beds having then an aggregate thickness of more than 300 feet.

Dry land, however, must have existed at all events near the spots where the coal was formed, inasmuch as

* See *ante*, p. 85.

the Ferns and Coniferæ could only be terrestrial plants. In addition to these, a land-shell called *Pupa* has been found in the inside of one of the upright trees of the

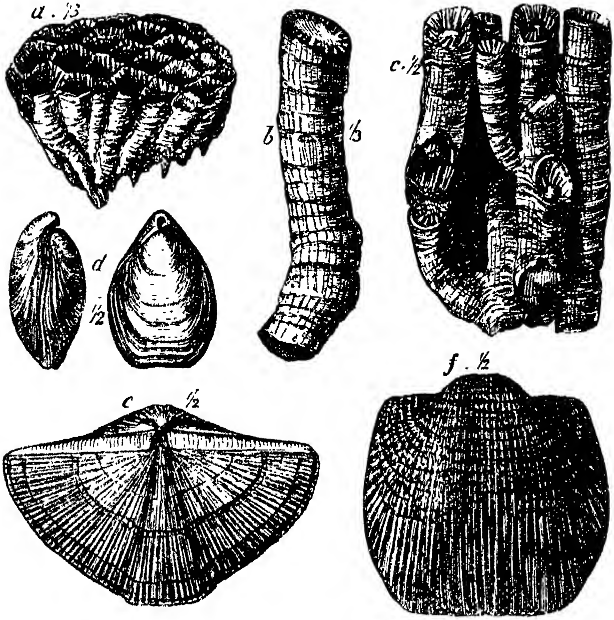

Fig 52.
Carboniferous Fossils.

a. Michelinia favosa.
b. Amplexus corralloides
c. Lithostrotion affine.
d. Terebratula hastata.
e. Spirifera striata.
f. Producta semireticulata.

Coal-measures of Nova Scotia, by Dr. Dawson, and several land-reptiles have also been found more or less nearly resembling lizards externally, but belonging, by

their anatomical relations, chiefly to an extinct order of the reptile class called Labyrinthodonta. Professor Huxley has lately described some larger Labyrinthodont reptiles found in the Carboniferous rocks of Scotland.

In Fig. 52 we have a few of the animal fossils of the Carboniferous rocks represented. The three first are Corals: *Michelinia favosa*, *Amplexus coralloides*, *Lithostrotion affine*, are very abundant in some parts of the limestone, and frequently make large masses. I have measured one of the last in Tipperary, which was nine feet in diameter (*figured in Explanation of Sh.* 145 *of the Geol. Surv. Ireland*). The other three—namely, *Terebratula hastata*, *Spirifera striata*, and *Producta semireticulata*—are all Brachiopodous bivalves.

These Brachiopoda have been several times mentioned. They were quite the most abundant of bivalve shells during the Palæozoic epoch, and perhaps the most abundant of all shells. They continued to be plentiful, both in species and individuals, till the commencement of the Tertiary epoch, when they became comparatively scarce, and they are rare, although still existing, in the seas of the present day. The animals are of a lower grade, or less highly organised, than the Conchifera (cockles, oysters, mussels, etc.) Their bodies are

---

Michelinia (*from M. Michelin*) favōsa (*honey-combed*).
Amplexus (*an embracing*) coralloides (*coral-like*).
Lithostrōtion (*stone-pavement*) affīne (*close together*).
Terebratŭla (*little bore-hole*) hastāta (*spear-shaped*).
Spiriféra (*spire-bearer*) striata (*striated*).
Producta (*produced shell*) semireticulata (*half-reticulated*).

thin and filmy, and they have two thread-like processes covered with vibratile cilia, which are supported in some genera, as in the Terebratulæ, on singular thin shelly loops inside the shells; in the Spiriferæ these were twisted into two spiral coils like watch-springs, each starting from the beak and proceeding to the end of the shell. In the Productæ the two valves were both curved in the same direction, so that the dorsal valve fitted into the ventral one, leaving but little room for the body of the animal, and none for any internal shelly process. In those which had spires, loops, or plates, however, both valves bulged outwards. The valves are differently arranged, with respect to the body of the animal, in the Brachiopoda and Conchifera. In the Brachiopoda they are like breast-plates and back-plates, and are hence called ventral and dorsal valves; while in the Conchifera they resemble two great shields, one on each side of the animal, and are thus spoken of as right and left valves. The consequence is, that as the animals are generally alike with respect to their sides, but differ in their front and back outlines, the shells of the Brachiopoda are generally equilateral but inequivalve, while those of the Conchifera are equivalve but inequilateral. In other words, a Brachiopod shell has usually the valves unlike each other, but each valve would be divided into equal and similar parts, or sides, by a line drawn through the beak at right angles to the hinge; but in a Conchifer the valves are generally alike, and equal to each other, while each valve would be divided into unequal parts by a line drawn as

aforesaid. The common Oyster is a conspicuous exception to this rule in the Conchifera, but the great majority of them follow it.

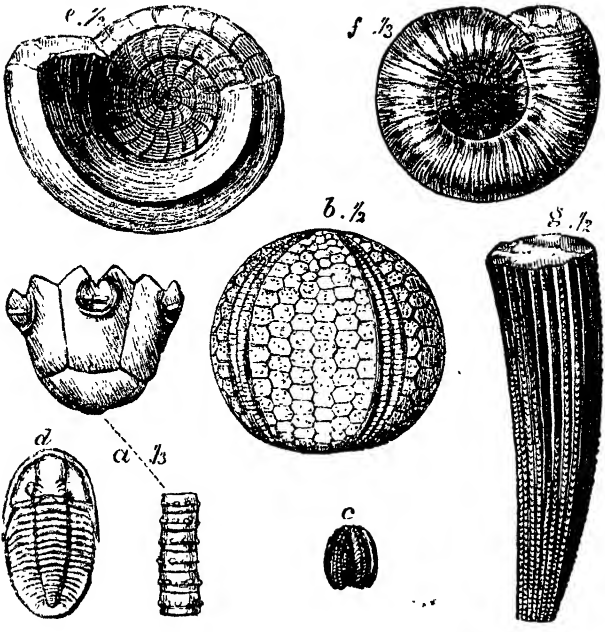

Fig. 53.
Carboniferous Fossils.

a. Platycrinus lævis.
b. Palæchinus sphæricus.
c. Pentremites Derbiensis.
d. Phillipsia pustulosa
e. Nautilus biangulatus.
f. Goniatites Listeri.
g. Orthoceras Gesneri.

Of the fossils figured in the cut No. 53, *e*, *f*, and *g*, are chambered univalves belonging to the class of

Cephalopoda. *Nautilus biangulatus* is a species of the same genus as the living pearly Nautilus, the divisions of which are simple and saucer-like, with a siphuncle, or little tube, in the centre of each division. The *Goniatites* differs from the *Nautilus* in the form of the divisions of the chambers (which are not shown in the figure), the edges of the saucer-like partitions being bent into sharp angles, and the siphuncle running near the back of the shell. The *Orthoceras Gesneri* is another curiously ornamented species of a genus of which other species have been found in the earlier rocks. Some of the Carboniferous species were as large as a man's leg. *Palæchinus sphæricus* greatly resembled the echini or sea-urchins of the present day, but differed in having five or six rows of interambulacral plates, whereas in recent species there are only two rows. Some other interesting forms have been discovered in these rocks, with overlapping plates, so that the test was movable like that of the remarkable Echinoderm recently dredged in the deep Atlantic. *Pentremites Derbiensis* was an animal of the same great class (Echinodermata), but more like some of the Cystideæ we have already seen. *Platycrinus lævis* was one of the great group of the sea-lilies that must have

Nautilus (*little sailor*) biangulātus (*two-angled*).
Goniatites (*angled shell*) Listĕri (*of Leister*).
Orthocĕras (*straight-horn*) Gesneri (*of Gesner*).
Palæchīnus (*ancient sea-urchin*) sphæricus (*spherical*).
Pentremītes (*five-oared*) Derbiensis (*of Derbyshire*).
Platycrīnus (*broad lily*) lævis (*smooth*).
Phillipsia (*from Prof. Phillips*) pustulosa (*pock-marked*).

waved their jointed stems and tufted heads in inconceivable abundance in some parts of the sea-bottoms of this period. They seem to have played the same parts as producers of limestone which reef-making Corals do now, since bed after bed of Carboniferous limestone, making long ranges of lofty hills, seem to be made up of little else than the broken and often half-obliterated fragments of these animals. In many of the crystalline marbles of this formation there is not a crystalline particle that will not, if examined by the lens, show a black spot like the mark of a pin's point, which is the central canal of some joint of a crinoid animal, and this mark often remains when the external form is lost. The figure 53 *d* is that of a trilobite *Phillipsia*, which, so far as we at present know, was one of the last of its order; there are only two other Carboniferous genera, and no species of trilobite has yet been discovered in any more recent rock than those belonging to this period.

In some parts of the Carboniferous limestone, and sometimes in the shales of the Coal-measures, the teeth of fishes are found; mostly of kinds belonging to the same order as that to which the existing Sharks and Rays belong, but some to the Ganoidei, an order which includes those with scales forming bony plates, like the Sturgeon; the Old Red Sandstone fish belong to this group. The mouth of a Ray is covered above and below with a pavement of flat teeth, either smooth, rough, or hooked, serving not only to catch, but to crush and grind the shells of the Crustacea and Mol-

lusca on which they live. There is one living species of Shark, the *Cestracion* or Port Jackson Shark, which has a similar pavement of palatal teeth. It inhabits the Australian seas, a part of the world where many of the older types of life still linger.

One of the charms of the study of geology is that, while it deals with the plainest matters of fact, it continually calls up to the imagination pictures of past events of which the general truth is certain, while all the details are left to fancy. That the limestones of the Carboniferous period were formed beneath the waves of a wide-spread sea is as certain a fact as that they now form the lofty cliffs at the foot of which the geologist pauses to examine them. The fossils they contain are the remains of animals that once lived and sported in those waves. The shales and sandstones were derived from the waste of the lands on which the Ferns and other plants grew; and those plants themselves, now compacted into the rock we call coal, secreted carbon from the ancient atmosphere while they were green with life and toying with the winds. The simple truth is like a fairy tale, the transformation like that in a pantomime, yet it is literal fact, while the time that has elapsed during its working out leaves far behind the wildest dreams of the romancer or the poet.

Permian Period.

As the rocks deposited during the Upper Silurian period are covered by a series of red sandstones and conglomerates, so the Carboniferous rocks are likewise covered by a series of precisely similar character. In the one case these red rocks have been classed together as *the* Old Red Sandstone, in the other they were at one time all grouped together as *the* New Red Sandstone. Whatever degree of similarity, however, there may be throughout a series of red sandstones, it has been found necessary to separate those originally called the New Red Sandstone into two groups, belonging not only to different periods, but to different epochs; these groups are the Permian and the Triassic or New Red Sandstone proper, the one being the newest of the Palæozoic series, and the other the oldest of the Mesozoic.*

The term Permian was derived by Sir R. I. Murchison from a district called Perm in Russia, where the rocks of the period, and their separation from the New Red Sandstone proper, are well shown.

In Germany they are separable into three divisions, called respectively Rotheliegende, Zechstein, and Bunter-schiefer—a nomenclature often used in other countries. This part of the series, as it exists in Britain, is very

* It has, however, been recently asserted that in some parts of England there is a greater break between the Carboniferous and Permian than between the Permian and the Trias; some geologists therefore would place the Permian in the Mesozoic series, and reinstate the New Red Sandstone period.

broken and imperfect, and must be taken to mark the place where a greater gap than usual exists in our records. In other words, one or two groups of rock are wanting in our area, which may, or may not, hereafter be discovered in other parts of the world.

Geographical Distribution. — In the British Islands there are two very distinct types of the Permian rocks, deposited under quite different conditions.

1. *Northern Counties.*—The first is that in the north of England, east and west of the Pennine chain, where they consist of three divisions :—

	England.		*Germany.*
3.	The Upper Red Sandstone	=	Bunter-schiefer.
2.	The Magnesian Limestone	=	Zechstein.
1.	The Lower Red Sandstone	=	Rotheliegende.

These groups are indicated in Fig. 49 as lying unconformably on the Coal-measures.

The Lower Red Sandstone, called in Germany the Rothetodtliegende (red-dead-layers) or simply Rotheliegende, rarely exceeds 200 feet in the north-east of England, but in Cumberland attains a thickness of 3000 feet.

Over this there is found, in Durham, a band of brown shaly marl, called the Marl slate, which is sometimes 60 feet thick. This often abounds with the remains of Fish, and it is remarkable that a similar group is also found in Germany, and there also called Marl slate (Mergel schiefer), which contains similar fish.*

* These beds are worked for copper (hence sometimes called Kupfer schiefer), and it is from the fact that the ore does not

The Marl slate forms the base of a series of calcareous beds which almost all consist of Magnesian limestone. This Magnesian or Dolomitic * character is so prevalent in this group in the north-east of England that it is therefore called *the* Magnesian Limestone, though large parts of the Carboniferous and other limestones are often quite as magnesian as any of the Permian limestones. The Magnesian Limestone of Durham is sometimes 500 or 600 feet thick, often mottled yellow and red, and sometimes strangely concretionary, the nodules taking the form of bunches of grapes, piles of musket or cannon balls, or other strange forms.

The Magnesian limestone stretches from the coast of Durham as far south as Nottingham, where it dies out. It occurs also as a thin band on the east side of the Pennine chain in Lancashire, and St. Bees' Head in Cumberland, where it is overlaid by thick red sandstones which range into the Vale of Eden and Scotland.

The Pennine chain, the rocks of which were described under the preceding period, had no existence till after the Permian period, and the comparative thicknesses of the beds on each side of it show that they extended right across from Yorkshire to Lancashire in a wedge-shaped fashion, the calcareous members

extend into the red sandstones below that the latter are called Rothetodtliegende.

* Magnesian Limestone, when it consists of nearly equal proportions of the two Carbonates, forms the mineral called Dolomite, after M. Dolomieu.

thinning out where the arenaceous beds thicken, as shown diagramatically in Fig. 54, where a = Lower Red Sandstone, b = Magnesian Limestone, c = Upper Red Sandstone.*

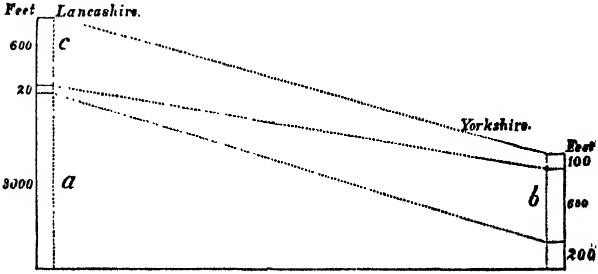

Fig. 54.
Comparative thicknesses of Permian beds.

2. *Midland Counties.*—The second type of Permian rocks is that of the central counties of England, where they consist of red marls, clays, and sandstones, with local breccias and conglomerates, having a maximum thickness of not much less than 2000 feet. These beds are wholly disconnected with the Permians of the North, being apparently deposited in a separate basin; they are supposed to belong exclusively to the Rothelie-gende division.

The section in Fig. 56 shows one form which these Permian rocks assume around part of the southern extremity of the South Staffordshire Coalfield. The trappean breccia is here so thick, and the fragments of trap

* See papers by E. Hull, Q. J. G. S., xxiv. p. 323; and Quart. Journ. of Science, No. xxiii. 1869, Ternary Classification.

so angular, that the Clent Hills were formerly supposed to be made of solid trap concealed by local debris only. Large angular fragments of Llandovery sandstone and other rocks, some of them brought, as Prof. Ramsay believes, by the agency of ice, occur in other parts of the district among these breccias.

Life of the Period.—Very few fossils belonging to this formation have been found in the deposits of the Midland Counties, only a few plants and remains of peculiar reptilian animals, similar to those occurring in the Triassic beds above.

In the north the Lower Red Sandstones contain large stems of plants, apparently the same as those in the Coal-measures. The fish-remains of the Marl slate have already been alluded to. Fig. 55 will give an idea of the forms of some of these fish, and of their beautiful state of preservation, their shining scales still glittering, and all the rays of the fins still in their places. *Platysomus*, *Cœlacanthus*, and *Palæoniscus*, all belong to different families of the same great order, which includes the Sturgeon and the Bony Pike of America (*Lepidosteus*). In these fish the back-bone is continued into the upper lobe of the tail-fin, and seems to form a part of that fin, instead of terminating entirely when the tail-fin commences, as in the Cod and Perch, and most of the fish of the present day. The latter character is called *homocercal* or regular-tailed, the former *hetero-*

Platysōmus (*broad body*) striatus (*striated*)
Cœlacanthus (*hollow spine*) granulosus (*granulated*).
Palæoniscus (*ancient oniscus*) comptus (*ornamented*).

cercal or irregular-tailed, and it is worthy of note that no specimen of a homocercal fish has ever been found in any bed belonging to the Palæozoic Epoch.

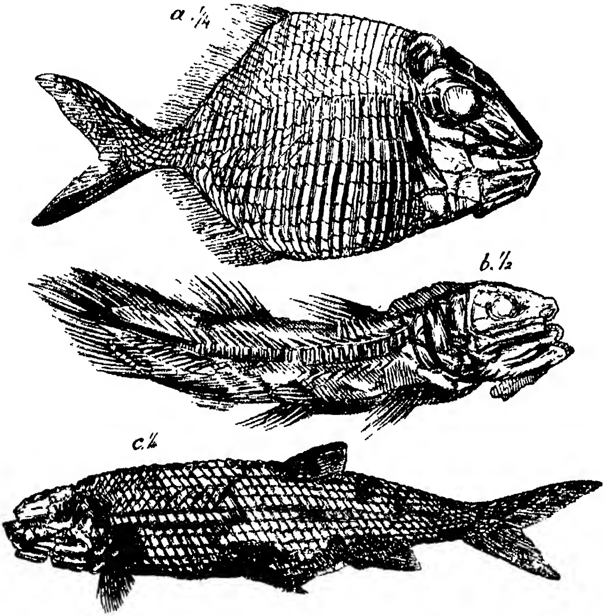

Fig. 55

Permian Fish.

a. Platysomus striatus. *b.* Cœlacanthus granulosus.
c. Palæoniscus comptus.

The Magnesian limestone is in some places fossiliferous, the species being peculiar to the deposit, though some of the genera are common to it and the Carboni-

ferous rocks below. The genus Producta is the most remarkable of these—one species, *Producta horrida*, being widely diffused in the Permian limestones of England and Germany. The remains of a reptile called *Lepidotosaurus* have lately been found in the Magnesian limestone of Durham, and another, called *Proterosaurus*, in the Marl slate. Numerous reptile-tracks have been found in the Upper sandstones at Corncockle Moor in Scotland, and are figured in a magnificent work published by Sir W. Jardine. No Trilobites have yet been found in any Permian rock.

Numerous plant remains have been found in beds which are supposed to belong to the Lower Permian series; they are mostly referable to Carboniferous genera, such as *Alethopteris* and *Neuropteris*, but the species are all different from those occurring in the coal-measures below.

On the whole, therefore, the organic remains of the Permian period more resemble those of the Carboniferous rocks than those of the Trias, and it is important to remember this in considering the relations of the Permian and Triassic series.

CHAPTER XVIII.

MESOZOIC OR SECONDARY EPOCH.

TRIASSIC OR THE NEW RED SANDSTONE PERIOD.

THE term New Red Sandstone is obviously a very bad name by which to designate a period of time. It does not much mend the matter, however, if we adopt the term Triassic, which the Continental geologists have brought into use, because the beds deposited during this period of time happen in some districts to be divisible into three groups. All these purely local and accidental characters, derived from the colour, or nature, or divisions of the rocks of particular districts, will ultimately be thrown aside as embarrassing, and a more general and scientific nomenclature introduced. Until this is done, however, we must necessarily use the words which have grown into general acceptation, and the name of Trias is less objectionable than New Red Sandstone, which formerly included both Permian and Trias.

Unconformability.—As all the separations in the series of stratified rocks are founded on the occurrence of breaks in their sequence, it follows that the account of the beginning and the ending of each great division must be obscure and unsatisfactory. This was the case

in the history of the Palæozoic Epoch, and it will be so here.

Each group of beds which were deposited in regular succession with only ordinary intervals between them, is intelligible in itself, and can be easily described, since it represents a certain order of things established within a given area. But it is often difficult to give even a guess at what took place between one established order of events and another. A bed of rock proves its own formation, and that a sufficient time elapsed to allow of that formation; but an interval in which nothing was formed necessarily leaves us no means of measuring its length.

On the other hand, these intervals of non-production, or perhaps of actual destruction of that which had been previously produced, are useful as giving us boundaries or division lines by which a series can be grouped into parts that would otherwise have been interminable, and therefore almost indescribable. While we use these gaps in our series for this purpose, however, we must be careful not to abuse them, which we should do if we came to the conclusion that because they give us only negative evidence they are to be taken as proof that nothing happened.

It will be recollected that in Chapter XII. the unconformability of one group of rocks to another was shown to be good evidence of a great interval having elapsed between their times of deposition. Now there is not anywhere in the structure of the British Islands a more marked and widely spread unconformability

than that between the Triassic strata and the Carboniferous and older deposits of the Palæozoic epoch. The originally horizontal beds of the Coal-measures had been bent into basins and domes, troughs and ridges; the Carboniferous limestone, covered at one time by so great a thickness of these Coal-measures, had been in some places entirely denuded of them, and deep valleys worn into it; and even the Old Red Sandstone and other formations beneath it had been laid bare over wide areas, before the deposition of some of the beds of the period we are now about to describe. Much disturbance and denudation of the Carboniferous rocks had taken place even before the Permian beds were deposited, and these themselves had likewise suffered along with the others, before the Triassic Period. Throughout England and Wales, and the North of Ireland, and probably in parts of Scotland, as well as here and there through the greater part of Europe, clear evidence of these facts can be obtained.

The section, Fig. 48, of the rocks about the Bristol coalfield, and the section, Fig. 71, of the valley of Belfast, will serve to illustrate these statements, and show that the Trias sandstones in each case rest upon a previously formed surface of erosion that had been made for its reception across the edges of the Palæozoic rocks.*

* I have been a little more particular in describing the unconformability between the New Red Sandstone and the Carboniferous rocks than in the case of other formations, because a point of great practical importance is involved in it. If the Permian and Triassic rocks were always conformable to the

Subdivisions of Period.—The three groups of rock which appear in Germany are there described as follows :—

3. Keuper marls and sandstones, of green, red, and various colours, with beds of impure coal ; having in some places a total thickness of 1000 feet.
2. Muschelkalk, or shell limestone, a reddish-grey rock, often very fossiliferous, and sometimes 600 feet thick.
1. Bunter (*variegated*) sandstone, red and white sandstone with thin marls, sometimes 1500 feet thick.

The Triassic series, as it appears in the centre of England, consists of the beds described in the following section, Fig. 56. This is a section across the Clent Hills, and part of Worcestershire to the south of them. It happens that along the southern margin of the south Staffordshire coalfield there is no apparent unconformity between the Carboniferous and Permian rocks, and the discordance between the Permian and the Trias is only perceptible when the country is carefully mapped. The

Coal-measures, it would be reasonable to expect that the latter, and probably, therefore, beds of coal in them, would always be found by sinking through the upper formations. Large sums of money have actually been expended in sinking pits with this expectation in places where, in consequence of this previous denudation, the rocks now lying immediately under the New Red Sandstone must be Carboniferous limestone, Old Red Sandstone, or some still older and lower formation, as would be the case at either end of the section in Fig. 48 for instance.

lower beds of the Trias, which are believed to correspond with the Bunter Sandstein of Germany, consist of brick-red sandstones and conglomerates or pebble beds, which, like all other conglomerates, vary in different places in their thickness and disposition. The upper part, which is identified with the Keuper of Germany, has a band of whitish sandstone about its base, the remainder consisting of thick red and mottled marls, which contain some beds of gypsum, and very

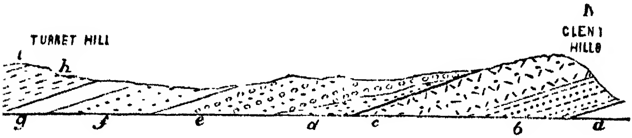

Fig. 56.

Section of the Permian and Triassic beds of North Worcestershire.

		Feet.
Oolitic.—	*i.* Lias.	
Keuper.	*h.* Red marls, with rock-salt and gypsum . .	500
	g Waterstones, white freestone with thin brown sandstone and marl	200
	The Muschelkalk is absent in England.	
	. .	300
	...ft brick-red sandstones, varying from 0 to .	550
Permian.	*c.* Tr...	
	b. Red marls and sandstones with cornstones	
Carboniferous—	*a.* Coal-measures.	

frequent veins and strings of that mineral, and also the great beds of rock-salt so well known and long worked in different parts of England.

In the Worcestershire salt district, of which Droitwich is the centre, the salt is got from brine springs and wells, no mines having been sunk into the solid rock-

salt, from the solution of which the brine undoubtedly proceeds. In the Cheshire salt district brine springs and wells are very numerous near Nantwich, but about Northwich the rock salt is got by mining. It occurs there in two great beds, the uppermost of which is about 80 feet and the lowest about 100 feet thick, with 30 feet of indurated clay between them. Where brine springs are numerous, the surface of the ground often shows hollows caused by its sinking in over those spots from which the rock-salt has been removed by solution.*

Above the Keuper marls in the south-west of England are found a few beds of shale and impure limestone, never more than 100 feet thick, which really form beds of passage between the Trias and Lias, but are now generally grouped with the former. These are called the Penarth or Rhætic beds, being well shown at Penarth on the Severn, and having thick equivalents in the Rhætic and Eastern Alps.

Life of the Period.—Fragments of fossil wood are not unfrequent in some parts of the Keuper sandstone of England, and fossil fish have been found in it; but the most remarkable traces of organic life are tracks or footprints of animals, which are beautifully preserved on the surface of some of the flagstones. These footprints seem to be always those of Reptiles; some of them resemble the form of a very fat coarse hand, the thumb being distinctly marked and turning away from the four fingers.

* See Mr. Ormerod's paper on the Cheshire Salt District, Q. J. G. S. L., vol. iv.

At the Stourton quarries, near Liverpool, a regular succession of prints of two small hands and two large ones were exposed about the year 1838, forming tracks 20 or 30 feet long. The quarrymen said they supposed they were the marks of "some one crawling away from the Deluge." Any one looking at the foot of a frog will at once be struck with its curious resemblance to the form of the human hand; and, as these tracks were evidently those of a four-footed animal, they are now universally attributed to some large amphibious creature belonging to the same great class as the frogs. The largest of the footprints is about 8 inches long, with a width of stride of about 14 inches. Bones and teeth also have been found in the Carboniferous, Permian, and Triassic rocks, belonging to animals that seem to have been great Amphibia, and from the curious internal structure of the teeth have been called Labyrinthodonta (*labyrinth-toothed*) by Professor Owen. This order of Labyrinthodonta is not only extinct now, but seems to have become extinct at the close of the Triassic period, since neither teeth, bones, nor tracks, that can be referred to it, occur in any subsequent deposit.

There have been found in the State of Connecticut, in America, in red shales and sandstones that are believed to be somewhere about the age of the upper part of the Trias, other tracks which seem to have been the footprints of large birds, some of which are supposed by Dr. Hitchcock to have been four times the size of an Ostrich.

The most characteristic fossils of the Penarth beds are *Avicula contorta*, *Pecten Valoniensis*, and *Cardium Rhæticum*. The upper Trias and Rhætic beds of the Eastern Alps abound with most remarkable organic remains intermediate in character between those of the preceding and subsequent periods.

Lie and Position of Trias.—The Trias seems to be very partially and imperfectly developed in Scotland, but it is fully represented in the Valley of the Laggan, and Belfast Lough in the North of Ireland, the Bunter sandstone being at least 600 feet thick, and covered by an equal thickness of red marl, containing near Carrickfergus two beds of rock-salt equal to those of Cheshire. Similar beds and veins of gypsum also occur in it, and it is in like manner capped by the basal beds of the Lias (see section, Fig. 71).

It is important to note the range of the Trias through England. Commencing at the mouth of the Tees on the borders of Durham and Yorkshire, it runs from Stockton and Darlington due south by York to Nottingham. From Nottingham it spreads in the Midland Counties, sweeps round the southern termination of the Pennine chain, and extends through Cheshire between that chain and the hills of the Welsh border, and along the coast of Lancashire to Morecambe Bay. In the Midland Counties the sandstone plain

Avicŭla (*little bird*) contorta (*twisted*).
Pecten (*a comb*) Valoniensis (*name of a place*).
Cardiŭm (*a heart*) Rhæticum (*Rhætic*).

is occasionally interrupted by islands of Palæozoic rocks, especially those of the Leicestershire, Warwickshire, South Staffordshire, and Shropshire coalfields; thence it runs in a narrower band down the Valley of the Severn, and across Somerset to the mouth of the Exe in Devonshire.

The lower part of the Vale of Eden in Cumberland, the Clwyd valley in Denbighshire, and that of Belfast in Antrim, are outlying districts, each containing characteristic deposits of the formation which are nearly horizontal, while hills of contorted Palæozoic rocks rise up from beneath them on either hand.

The richness and fertility of its soil, joined with its proximity to mines of coal and metal in the Palæozoic rocks, make the Trias district one of the most populous in England, and one in which many of the chief manufacturing towns are situated.

If we draw a line on a geological map along its eastern boundary, from the mouth of the Tees to that of the Exe, all the country to the south-east of that line differs from that to the west and north in external features, in mineral resources, in the nature of the soil, in the occupations, the manners, and even the dialect of the inhabitants. Scotland, Ireland, Wales, and England, to the west and north of the boundary line, are irregular in outline, with varied mountains, hills, and plains, running in different directions. The rocks below the surface are even still more irregular than the external features, while over their highly inclined and greatly eroded edges the Trias lies in

nearly horizontal layers throughout its area; and from the boundary line mentioned above, its beds dip gently towards the south-east, forming a floor, as it were, on which the deposits of the Secondary and Tertiary Epochs rest, mostly with an equally gentle inclination towards the east. The hills and ridges, and the intervening plains, of this eastern district, run chiefly in long continuous lines parallel to the boundary of the Trias.

Neither coal-mines nor mineral veins occur to the eastward of this boundary line, the only mining processes being those of open quarry work chiefly for building materials, though some important deposits of iron ore are now also worked by quarrying in this part of the country.

It is to the country lying to the east and south of this boundary line that we now turn our attention.

NOTE.—In order to understand what has been hitherto said of the geological structure of the British Islands, it will be necessary to refer occasionally to a geological map of them. Professor Ramsay's map of England and Wales, and the smaller one by Sir R. I. Murchison; Professor Nichol's map of Scotland, or the clearer one by Sir R. I. Murchison and Mr. Geikie; and Sir R. Griffith's map of Ireland, of which there is one large and one small cheap edition, are all excellent authorities. Mr. Knipe's geological map of the British Islands is also a useful wall map.

CHAPTER XIX.

JURASSIC OR OOLITIC PERIOD.

The term Jurassic is used for the rocks of this period by the Continental geologists, because the well-known mountain range known as the Jura, which runs in a curve along the N.W. frontier of Switzerland, is composed of them.

The term Oolitic refers to the lithological structure of some of the limestones in the district which is now the south of England. These are composed of oolite or roestone (see p. 81). It must not be supposed, however, that all the limestones of this period are oolitic, or that no limestone of any other period is so. Large parts of the Carboniferous limestone of Ireland are as perfectly oolitic as the Bath stone, and I have seen the structure well developed in the recent limestone of a Coral reef.

Lie and Position of Beds.—It will be sufficient for us to confine our attention to the British area, and the history to be learnt from it. If we were to follow the upper boundary of the Trias mentioned in Chapter XVIII. as running through England from the coast of Yorkshire to that of Devon, we should always find that the red marls dipped to the east, and became

covered in that direction by some beds of grey shale or clay. This clay is the lower part of a group called the Lias, which stretches continuously across England from the cliffs of Whitby in Yorkshire, to those of Lyme Regis on the coast of Dorsetshire. Its beds dip gently to the east, and become covered in that direction by sandstones and oolitic limestones.

One of the best districts for studying these beds is that which lies about Cheltenham, and between it and Bath, where the rocks which lie above the Lias form high ground, part of which is known as the Cotteswold Hills. This ground rises slowly from the east until it attains an altitude of about 600 or 800 feet above the sea, and then suddenly terminates in a bold escarpment sloping abruptly to the west, and looking down upon the broad Valley of the Severn. This escarpment is deeply indented by small narrow branching valleys which penetrate it from the west, while bold capes and promontories and outlying hills advance from it towards the west into the region of the low land.* As the different beds of rock dip eastward at a very low angle—but little steeper, indeed, than the inclination of the ground on the long eastern slope of the hills—it follows that these numerous valleys on the one

* The brooks which issue out of these valleys into the low lands on the west form tributaries to the Severn, but those formed by the waters on the summits of the hills naturally tend to run down the long eastern slope, and are tributaries of the Thames. What is called the source of the latter river is shown in a spring on the back of the Cotteswolds, a few miles south of Cheltenham.

hand, and the outlying hills on the other, must afford in their sides excellent opportunities for tracing the different beds and comparing their outcrops at different places, and thus getting a perfect knowledge of their composition, their extent, their order of superposition, and the fossils and minerals which they may contain.

It was in fact in this very district that the knowledge of true stratigraphical geology, in England, was commenced by the labours of the late Dr. William Smith, so that it must always be considered classic ground by the English geologist.

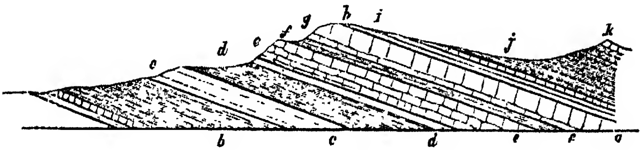

Fig 57.

Diagrammatic Section of the Gloucestershire Oolites.

	Feet.		Feet.
k. Coral rag .		*e* Inferior Oolite . .	236
j. Oxford clay .		*d* Upper Lias sand and shale	300
i. Cornbrash .		*c*. Marlstone . . .	200
h. Forest Marble		*b*. Lower Lias shale . .	600
g. Great Oolite .		*a*. Red Marls (being the upper part of the Trias).	
f. Fuller's earth			

Subdivisions of Period.—Combining the knowledge acquired from the examination of the structure of Gloucestershire, and parts of the adjacent counties of Oxford and Worcester, we are enabled to condense it into the preceding diagrammatic form (Fig. 57), which represents the different groups of rocks in their

natural order of occurrence, with the maximum thickness which each attains as it is traced through the district. It is obvious that it is right to take, in all cases, the maximum thickness of a group as that which is likely to give us the most complete account of the history of its formation. It is there where the greatest number of records were deposited, or where they have been best preserved.

Each of these groups is liable to variation in its nature and thickness, and each may altogether die out and disappear in different directions, and be replaced perhaps by some other set of beds of a different character. For this reason, among others, it is generally advisable to unite those that have certain characters in common into larger groups under some common designation, which they may retain independently of the variation of their several members.

The following Table will show this classification of the Jurassic or Oolitic series, with the average maximum thickness that may be assigned to the several groups :—

		Feet.		Feet.
The Jurassic system, 4000 feet.	*D.* Upper or Portland Oolites . . .	950	13. Purbeck beds .	200
			12. Portland beds .	178
			11. Kimeridge clay	600
	C. Middle or Oxford Oolites . . .	900	10. Coral rag . .	300
			9. Oxford clay .	600
	B. Lower or Bath Oolites . . .	1250	8. Cornbrash . .	40
			7. Forest marble .	450
			6. Great Oolite .	140
			5. Fuller's earth .	400
			4. Inferior Oolite .	230
	A. The Lias . . .	1200	3. Upper Lias .	400
			2. Marlstone . .	200
			1. Lower Lias . .	600

The Lias.—The groups *b*, *c*, *d*, are thus united as "The Lias," which is essentially a great clay deposit, with occasional bands of argillaceous limestone (good for hydraulic lime) near the base, and some hard sandy rock called the Marlstone near the middle. Near Bath the Upper Lias shale dies out, and there is no clay between the Marlstone and the Inferior Oolite, the intermediate sands being supposed by some persons to belong to the Oolites above, while by others they are classed with the Lias below. The Lias probably retains an average thickness of at least 500 feet all across England.

Lower or Bath Oolites.—The groups *e*, *f*, *g*, *h*, and *i*, are in like manner to be classed together as the Lower or Bath Oolites, characterised over a certain area by the occurrence of oolitic or shelly or flaggy limestones, separated by variable bands of clay and sand. The group *e*, or Inferior Oolite, which contains the Pea grit and beds called Ragstone and Freestone near Cheltenham, dies out towards Oxford and disappears. In Northamptonshire and Lincolnshire, however, it re-occurs with a base of sand and brown ironstone, now largely worked for smelting, above this is the Colly-weston slate, followed by a thick series of limestones which afford many valuable building stones, such as those of Ketton and Barnack. The group *f* or Fuller's earth, a series of clays and marls, does not extend nearly so far, but disappears within the Gloucestershire area, and allows the Great Oolite to rest directly on the Inferior Oolite. In Dorsetshire, however, the Fuller's earth attains a thickness of 400 feet.

The Great Oolite, from which the well-known "Bath stone" is derived, spreads apparently over a wider area. The flags known as "Stonesfield slate" in Oxfordshire belong to its lower part; and good free-stone for building is got from the same group in Somersetshire. The little group *h* is called the Forest Marble, from Wychwood Forest in Oxfordshire, and consists of thin beds of clay and shelly limestone from 50 to 60 feet thick. It becomes insignificant in the south of Northampton, but in Lincolnshire the clay beds re-appear and have been mapped under the name of the Great Oolite clays. Near Bradford there is a local development of clay between the Forest Marble and the Great Oolite which was formerly celebrated for some beautiful fossils found in it. This division is also very thick in Dorset, including about 450 feet of strata.

The Cornbrash, a local name given to the stratum, seems thin and insignificant, but it appears to have a wider range than any of the others, for it is believed to spread from Dorsetshire to Yorkshire; Mr. Judd, however, has pointed out that it is absent in the southern part of the latter county.

In Yorkshire the Lower Oolites form a series of sands and clays, with beds of impure coal, having a total thickness of some 800 feet. They are altogether different from those in the south-west of England and more resemble the Coal-measures of the Carboniferous period; they might in fact be called the Oolitic Coal-measures, and form just as good an instance of the

lateral change that may take place in a series of beds as that of the Carboniferous Limestone of England passing into the lower Coal-measures of Scotland.

Middle or Oxford Oolites.—The groups *j* and *k*, the Oxford Clay and the Coral Rag, are in like manner classed together as the Oxford or Middle Oolites. The Oxford Clay is a dark-grey clay deposit, which retains its character and thickness more or less completely all across England; it has in some places a band of hard stone in its lower part, called Kelloway rock, from a place in Wiltshire. The Coral Rag, on the other hand, is a variable and capricious band of sands and coarse limestones, which in some places abound in fossil corals, mostly in the position of growth.

Upper or Portland Oolites.—The Oxford Clay and the Coral Rag, when traced into Dorsetshire and the headlands of Portland and Purbeck, are found to be there covered by other beds, as shown in the diagram given in Fig. 58. The Kimeridge Clay is a dark-grey shaly clay, with layers of sand, and sometimes thin impure coals; it is named from Kimeridge Bay, on the coast of Dorsetshire, where it is well seen, and it may be followed thence into Buckinghamshire and Cambridgeshire, where it seems to die out or becomes excessively thin, regaining importance, however, in Lincolnshire and Yorkshire. The Portland Sands rest on the Kimeridge Clay, and may be traced as far North as Shotover Hill, near Oxford. In the Isle of Portland they are covered by the Oolitic Limestone, well known as an excellent building stone under the name of the

Portland stone. The Purbeck beds consist of shelly limestones with some shales and some remarkable beds of "soil," called "dirt-beds" by the quarrymen. These are to be seen a little above the top of the Portland

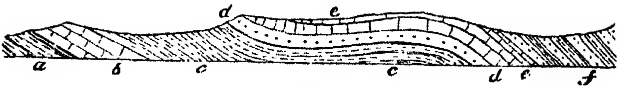

Fig 58

Diagrammatic section of Dorsetshire Oolites.

	Feet.		Feet.
f. Wealden sands and clays	1400	*c.* Kimeridge clay . . .	505
e. Purbeck beds	150	*b.* Coral rag	300
d. Portland stone and sands	150	*a.* Oxford clay	600

stone in the isles of Purbeck and Portland; in the former they are over 300 feet thick. Neither the Portland stone, however, nor the Purbeck beds above it, are known to exist north of Dorsetshire.

It is remarkable that while the fossil shells found in the Portland stone, and all the beds below it, down to the Trias, are almost entirely marine shells, those of the Purbeck beds are fresh-water and estuary forms.

Life of the Period.—The rocks now described are all full of fossils. Many fragments of plants are found in them, some of which have a general resemblance to those found in the Carboniferous series, although none are absolutely identical with them. Several of the genera of plants found in the Carboniferous rocks, however, are not found in the Oolitic, while other genera are found in the Oolites, which are not found in any earlier deposit, but are more like plants that now exist in some part or other of the globe. The animal fossils

are not only more numerous than the plants, but much better preserved. Corals, shells of all kinds of Mollusca, Echinodermata (star-fishes, sea-lilies, and urchins), Crustacea (crab, lobster, and shrimp class), Annelida (worm class), Insects, Fish, Reptiles, and Mammals (animals that suckle their young)—all these, and almost every other class of the Animal Kingdom that had any hard parts capable of preservation, have representatives among the fossils of the Oolites.

These remains are of great interest, both in themselves as additions to the existing Animal Kingdom, and also when compared with the other extinct races in the rocks below and above them. Looking at the preceding table, we may say, in the first place, that with very few exceptions the whole assemblage of fossils found in the Oolitic series is peculiar to that formation. Not a single species found in any earlier deposit in the British islands has ever been found in the Oolites. All the preceding species, then, must have died out and become extinct before the commencement of the Oolitic period. Again, almost all the species which abounded in this period, certainly all those found in its lower and earlier members, died out and became extinct before the commencement of the next or Cretaceous period.

If we look to those groups of species which are called genera, we find that many of these which existed in the preceding periods, such as *Producta* among Brachiopodous bivalves, *Orthoceras* and *Goniatites* among Cephalopodous univalves, were also extinct before the commencement of this period. Other genera which

were the contemporaries of these, such as *Spirifera* among the Brachiopoda, still survived, but the species of Spiriferæ found in the Jurassic rocks are manifestly different from those in any preceding deposit, and even those are only found in the earlier or lower parts of the Jurassic series, so that they died out, in our area at least, soon after the commencement of the period.

Other genera, which have never been found in the British islands in any earlier deposit, such as *Ammonites* and *Belemnites* among Cephalopodous shells, many ordinary bivalve and univalve shells, and many of a higher class of animals, appear now to have first come into existence. Most of these survived as genera into succeeding periods, and many even to the present day—species after species having successively appeared and died out during the intervening time. Among bivalve shells the genera *Corbis*, *Astarte*, *Isocardia*, *Lima*, and *Trigonia*, may be mentioned; among univalves the genera *Cerithium*, *Nerita*, and *Solarium;* while the reptile genera, *Chelone* (Tortoises or Turtles), *Trionyx* (Soft-tortoises), and *Lacerta* (Lizards), might also perhaps be given as instances.

Many large reptiles, however, lived during this period, of which not only the species and the genus, but even the order, are not only extinct now, but were so at the commencement of the Tertiary Epoch.

There was a huge land reptile called the *Megalosaurus* (*great reptile**), which, from the size of its

* Saura or Sauros is the Greek word for a lizard, but it is used by naturalists to denote not only real lizards, but all the

fossil bones, must have been sometimes as much as 30 feet in length, and must have had other large land animals to prey upon, if we judge from its large backward-curved serrated teeth, which seem like a combination of knife, saw, and sabre, intended to hold a struggling prey as well as to tear it and cut it.

There were also several kinds of great marine carnivorous reptiles, that were obviously intended to pass their lives in the sea almost as entirely as the existing marine mammalia, the Porpoises and Whales. In these the legs and paws are shrunk up, as in the Whales, and enclosed in a mitten-like skin, so as to make a flipper or paddle instead of a leg and foot.

One genus of these reptiles is called the *Ichthyosaurus* (*fish reptile*). These must have resembled a Grampus in shape, but had hind-flippers as well as fore, while the whale tribe (*Cetacea*) have only fore-flippers. They had also a tail-fin like the Whales, but, unlike them, it seems to have been a vertical one as in fish, while the whale animals have theirs horizontal. Thick and strong about the shoulders, with scarcely any neck, but tapering in each direction, the Ichthyosaurus must have been well adapted to cleave the waters of the ocean, while his large eye would enable him to discern his prey or his enemy even in deep water. His eyeball was surrounded by a circle of bony plates that probably acted not only as a defence to the organ, but, like those in the eyes of birds of prey, to

lizard-like reptiles, including alligators and crocodiles, so that always to translate it by "lizard" would lead to misconception, unless we include the crocodiles, etc., under that term.

assist in giving a varied range of vision. The whole pointed muzzle, from the eye to the snout, opened with a great gaping mouth armed with a thick row of round conical teeth set in a jaw of numerous long bones "fished" together, so as to combine strength and flexibility, every tooth having the germ of another beneath it, always ready to grow into its place when it was worn out or broken. Many whole skeletons of small Ichthyosauri have been dug out of the Lias shales with the bones scarcely moved from their places, and in some even the marks of the skin preserved on the surface of the rock. Judging from these and the relative size of other single bones or detached parts of skeletons, some of the Ichthyosauri must have been 30 feet long. There were, however, many species of them —as many as thirty, according to Professor Owen, having been found in the rocks of this period and the next.

The *Plesiosaurus* (*near a reptile*) was like the Ichthyosaurus, so far as his flippers or paddles and the other main points of his structure are concerned, but his body and head were comparatively small, while his neck was excessively long, having no fewer than thirty-three vertebræ. The tail was much shorter than that of the Ichthyosaurus, and the paddles longer and narrower. He was obviously not so powerful a swimmer as the other, but probably lurked in more shallow seas, and seized his prey by darting forward his head by means of his long flexible neck. More than twenty species existed during the Oolitic and Cretaceous periods.

There are many other genera of reptiles in the Oolitic rocks, some of them more like our Crocodiles, others resembling our Tortoises or Turtles; but the most extraordinary of all is the flying reptile called the Pterodactyle.

The *Pterodactylus* (*wing finger*) was a true Saurian with long jaws and sharp teeth, but was enabled like the Bats to flit through the air by means of an extension of the skin spreading from the fore to the hind leg on each side. In the Bats, however, the whole of the digits of the fore-paw are greatly elongated for the reception of the web or skin, while in the Pterodactyles the joints of the fifth digit only (answering to the little finger in our own hands) were thus elongated. The Pterodactyles found in the Oolitic rocks seem to have varied in size from that of a snipe to that of a cormorant, but those found in some of the Cretaceous series, near Cambridge, were very much larger. It thus appears that even the flying dragons of romance have had something like a real existence in former ages of the world.

No bones of Birds have yet been reported from any of the Oolitic series in England. The occurrence of the bones of an animal having such facile powers of locomotion, and of which even the dead body floats, must always be rare. In the lithographic shales of Solenhofen in Bavaria, which are believed to be the equivalents of our Coral Rag, and are very rich in organic remains, a fossil was discovered that was at first considered to have been a feathered reptile, from

its possessing a long tail with twenty caudal vertebræ, surrounded with distinct impressions of plume-like feathers. Wagner and Professor Owen, however, have shown that it has so much of the bird character in its structure, that, notwithstanding the reptile-like tail, it was probably a Bird. It was called by Wagner *Archæopteryx macrurus.*

Mammalian remains have been found in the Stonesfield slate in Oxfordshire, and also in the Purbeck beds in the Island of Purbeck, where they were especially quarried for by Mr. Beckles. These Mammalia seem to have been chiefly small marsupial animals, either carnivorous, insectivorous, or phytophagous, like some of these now living in Australia and Tasmania; but one of them, called *Stereognathus Ooliticus*, is believed by Professor Owen to have been possibly a hoofed herbivorous mammal of the higher or Placental sub-kingdom.

It is a very curious fact that not only these marsupial animals, but several of the shells—as for instance the Trigonias, and even some of the plants, found fossil in the Oolitic rocks—much more nearly resemble those now living in Australia than the living forms of any other part of the globe. This might be explained on the supposition that since the Oolitic period less change had taken place in Australia than elsewhere, and that the Australian Fauna and Flora consequently retained something of the Oolitic type, while it had

Archæoptĕryx (*ancient bird*) macrurus (*long-tailed*).
Stereognathus (*strong jaw*) oolitĭcus (*oolitic*).

been altogether supplanted and replaced in the rest of the globe.

The general statements now given as to the fossils of the Oolitic series have an obvious interest, but closer examination will disclose facts still more remarkable. Not only is the total assemblage of fossils found in the Oolitic series quite distinct from that found in any other series, but even the several members of the series have each a distinct assemblage of fossils.

Taking the greater divisions *A*, *B*, *C*, *D*, of the table on p. 292, the majority of the Lias fossils are quite distinct from the majority of those in the Bath Oolites, and those again from the fossils of the Oxford Oolites, and those from the Portland fossils. A few species range from one division into the next, still fewer into a third, just sufficient to link them together and give them something in common. Their connection, however, is better marked by genera than by species, which means that many of the different species found in the different groups are, although distinct, yet so nearly allied as to make a genus, which is either peculiarly Oolitic, or is more abundantly represented in species and individuals in the Oolitic rocks than elsewhere. But not only are these greater divisions characterised by containing peculiar fossils, but even their subdivisions have each a certain set of species which are only found in the one subdivision. Neither does this local distribution of species stop there, for many of these subdivisions may be again divided into smaller sets of beds confined within a smaller area, and

these sets have also their peculiar species, which are, within that area, confined to the set, or, with respect to some of them, are not found anywhere else except in that little local bed or set of beds.

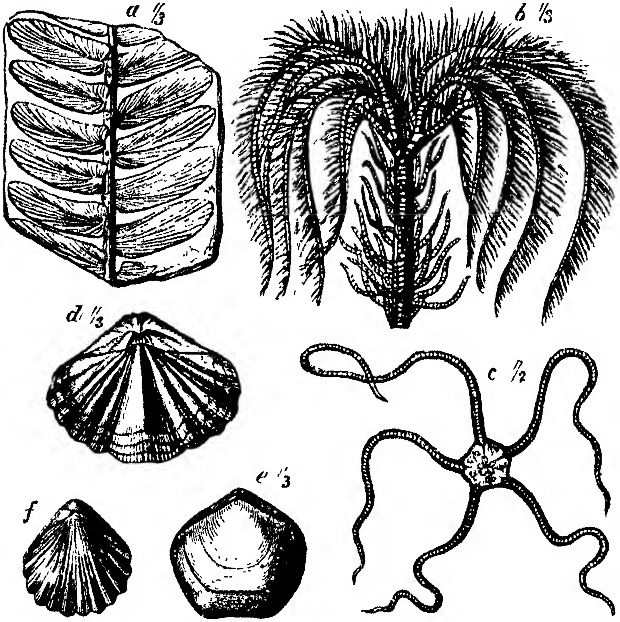

Fig. 59.
Lias Fossils.

a. Otopteris obtusa.
b. Extracrinus Briareus.
c. Ophioderma Egertoni.
d. Spirifera Walcottii.
e. Terebratula numismalis.
f. Rhynchonella rimosa.

It would take a large volume full of plates to give anything approaching to an adequate idea of the charac-

teristic fossils of the different groups of the Oolitic series, but in the following figures a few examples of them are given.

Those in Figures 59 and 60 are Liassic fossils. *Otopteris obtusa* is a part of the frond of a fern. *Extracrinus Briareus* was one of the Crinoid or sea-lily family of the Echinodermata, the head of which, as shown in the figure, consisted of a cluster of branches fringed with filaments not unlike a *Comatula* (or *feather star*) of the present day, set on a five-sided jointed stem that was also fringed. They are very beautiful fossils, often occurring in clusters converted into iron pyrites, and looking like the most delicate bronze work. *Ophioderma Egertoni* belonged to another order of the Echinodermata, and very nearly resembles an *Ophiura* (or *brittle star*) of our own seas. *Spirifera Walcottii* was a brachiopodous bivalve, one of the last surviving members of a genus that was so numerous during the Carboniferous period. *Terebratula numismalis* and *Rhynchonella rimosa* are other extinct species of the same great class belonging to genera which still exist at the present day.

Avicula decussata, *Gryphæa incurva*, and *Hippopodium ponderosum*, are bivalves of the ordinary or conchiferous class. *Gryphæa incurva*, belonging to the

Otoptĕris (*ear fern*) obtūsa (*blunted*).
Extracrinus (*outside-lily*) Briăreūs (*hundred-armed*).
Ophioderma (*snake-skin*) Egertoni (*of Sir P. Egerton*).
Spirifĕra (*spire-bearer*) Walcottii (*of Walcott*).
Terebrătūla (*perforated shell*) numismālis (*like a coin*).
lla (*little beak*) rimōsa (*gaping*).

Oyster family, is especially abundant in the Lias, and almost absolutely confined to it. *Pleurotomaria An-*

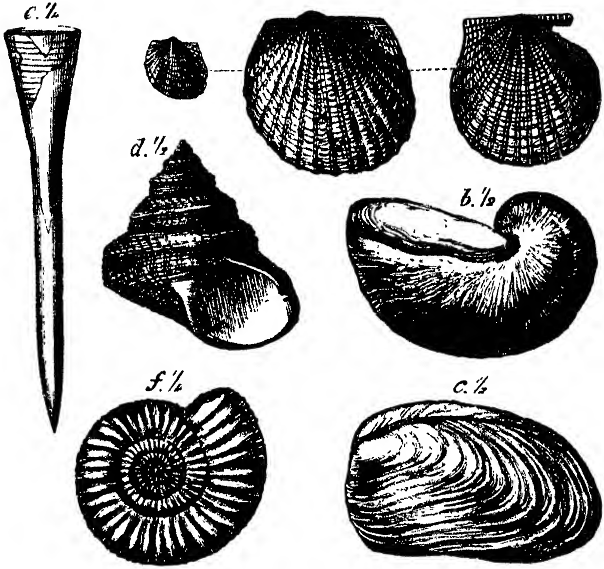

Fig. 60.

a. Avicula decussata. *d.* Pleurotomaria Anglica.
b. Gryphæa incurva *e.* Belemnites elongatus.
c. Hippopodium ponderosum. *f.* Ammonites communis.

glica belongs to a genus (see *ante*, p. 251) which commenced in the Lower Silurian and did not die out till

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Avĭcŭla (*little bird*) decussata (*ribbed crosswise*).
Gryphæa (*hook-nosed*) incurva (*bent inwards*).
Hippopodium (*horse-hoof*) ponderosum (*heavy*).
Pleurotŏmăria (*side slit*) Anglĭca (*English*).
Belemnītes (*a thunderbolt*) elongatus (*elongated*).

Tertiary times. *Belemnites elongatus* was part of the internal apparatus of a Cephalopod like the existing Cuttle-fishes, the lower part of it resembling in structure what is called the Cuttle-fish bone, only of a round conical shape, while the upper part was hollow and divided into chambers, and had a pearly sheath or cup proceeding from it, which enclosed the ink-bag of the animal. These ink-bags are sometimes found perfectly preserved, containing fossil sepia, with which drawings can be made of as rich a tint as with sepia taken from the recent Cuttle-fish. Some beds of Lias are completely paved with Belemnites. *Ammonites communis* (so called from the ram's horn on the head of Jupiter Ammon) is a shell belonging to another branch of the Cephalopoda, that to which the pearly Nautilus belongs. The shell is chambered like the Nautilus, but the septa or divisions between the chambers, instead of being plain like saucers, are variously indented and frilled at the edges, and the siphuncle or tube connecting them runs down the back of the shell instead of down the centre. These Ammonites are wonderfully numerous in the Oolitic and Cretaceous rocks, no fewer than about 600 species having been noted, while the individuals are sometimes so abundant as to make up the mass of the beds. They vary in size from that of a pin's head to that of a cart wheel.

Acrosălēnia (*hump salenia*) hemicidaroides (*like Hemicidaris*)
Apĭocrĭnus (*pear lily*) Parkinsoni (*of Parkinson*).
Ammonites (*Ammonites*) discus (*a disk*).
Pholădomȳa (*boring Mya*) lyrata (*lyre-shaped*).

The next group, Fig. 61, is from the Cornbrash and Forest Marble. *Acrosalenia hemicidaroides* is

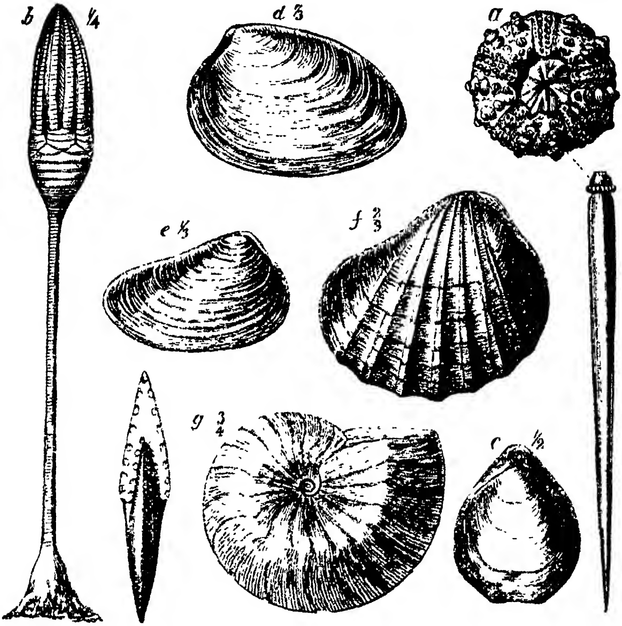


Fig. 61.
Cornbrash and Forest Marble Fossils.

a. Acrosalenia hemicidaroides.
b. Apiocrinus Parkinsoni.
c. Terebratula intermedia.
d. Gresslya peregrina.
e. Myacites decurtata.
f. Pholadomya lyrata.
g. Ammonites discus.

one of that order of Echinodermata which is still abundant on the earth, and commonly known as Sea Urchins. *Apiocrinus Parkinsoni*, on the other hand,

belongs to the Crinoidea or Stone lilies, which are now almost entirely extinct, although in former ages more abundant than the Echinoidea. Its form may be compared with the other examples of the order given in

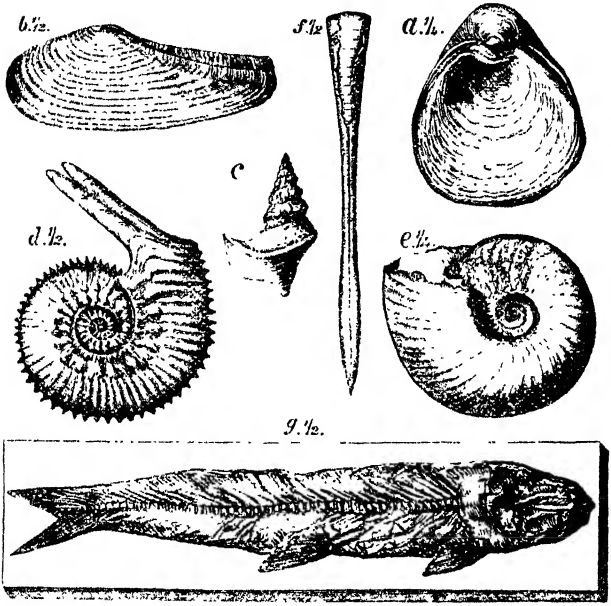


Fig 62.
Oxford Clay Fossils

a. Gryphaea dilatata. d. Ammonites Jason.
b. Anatina undulata. e. Ammonites excavatus.
c. Alaria composita. f. Belemnites hastatus.
g. Leptolepis macrophthalmus.

Figs. 43, 53, and 59. Fig. 61 *c* is another species of *Terebratula;* Fig 61 *d*, *e*, and *f*, are Conchifers; and

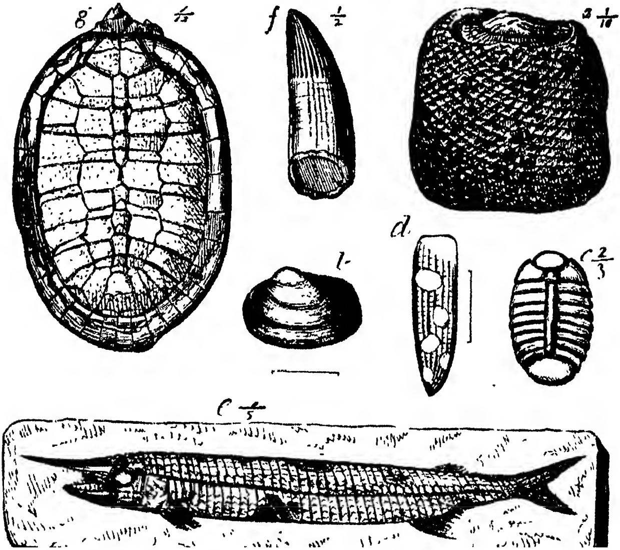
Fig. 61 *g*, *Ammonites discus*, is an example of a form externally very different from that previously given, although the main points of its internal structure are the same. The figure representing the shell viewed edgeways shows the pits along the margin caused by the indentation of the septa of the chambers, and also the siphuncle in the upper peak of the shell.

In Fig. 62 we have two other species of *Ammonites* remarkably different from those given before and from each other, Fig. *d* showing the curious shelly processes on each side of the mouth of the shell which are found when it is perfectly preserved. It is obvious that such fragile parts could only be preserved in fine clay. Some of the specimens from these clays retain even the iridescent colours of the shells, which are almost as thin and delicate as tissue paper. *Belemnites hastatus*, figured at *f*, is obviously different in shape and proportion from that in Fig. 60, and *Gryphæa dilatata* from the *incurved* one shown in Fig. 60. This dilated species is almost as abundant in, and characteristic of, the Oxford Clay, as the other is of the Lias. The fossil fish figured at *g*, and called *Leptolepis macrophthalmus*, may be compared with the fossil fishes shown at Fig. 55, p. 277, as showing a homocercal tail.

The following group of figures of fossils is introduced rather with a view to contrast than comparison. The beds were formed in fresh water, and the fossils are all either of land or fresh-water origin. *Cycadeoidea*

Belemnites (*thunderbolt*) hastatus (*armed with a spear*).
Leptolĕpis (*thin scale*) macrophthalmus (*large eyed*).

microphylla is the stool of a plant which, like the Cycas and Zamia of the present day, had long stalks and leaves



a. Cycadeoidea microphylla. *d.* Bupreston stygnus (elytron).
b. Cyrena elongata *e.* Aspidorhynchus Fisheri.
c. Archæoniscus Edwardsi. *f.* Goniopholis crassidens.
g. Pleurosternon ovatum.

branching from the scars on a short stump. These bodies are found in the dirt-beds of the Purbeck group, and

Cycadeöidea (*cycas-like*) microphylla (*small leaved*).

called crows' nests by the quarrymen. *Cyrena elongata* was a fresh-water or swamp shell. *Archæoniscus Edwardsi* is a part of a Crustacean resembling the existing wood-louse, and Fig. *d* is part of the elytron or wing shield of a beetle. Fig. *e* shows another fossil fish belonging to the old *Lepidostean* or *bony-scaled* type, and possessing a curious pointed snout ; *f* is a tooth of a crocodilian reptile, while *Pleurosternon ovatum* is obviously the shield of a Chelonian reptile which was, according to Professor Owen, most probably a large pond turtle.

But the limitation of peculiar species to certain beds is not confined to mere shells, corals, and echinoderms ; the different species of fish, and reptiles, and mammalia, are similarly limited, and indeed are even more closely restricted than the lower classes. A whole genus of animals called *Pliosaurus*, allied to the *Plesiosaurus*, but differing from it in the form of the teeth and cervical vertebræ, is almost peculiar to the Kimeridge Clay, several species having been found in that group, one of them apparently 40 feet in length. The Mammalia of the Stonesfield slate are also entirely distinct from those of the Purbeck beds.[1]

The main groups of the Oolitic series, as thus described, may be traced through France into Switzerland,

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[1] Cyrena (*proper name*) elongata (*elongated*).
Archæoniscus (*ancient wood-louse*) Edwardsi (*of Edwards*).
Aspidorhynchus (*spear-snout*) Fisheri (*of Fisher*).
Goniopholis (*angular scale*) crassidens (*strong-toothed*).
Pleurosternon (*rib-chest*) ovatum (*ovate*).

with a singular persistence in their lithological and palæontological characters. They also enter largely into the structure of the Alps, but are there altered into clay-slates with transverse cleavage, and into mica-schist and gneiss and metamorphic limestone called Alpenkalk, which are precisely like many of the much older gneiss and mica-schists and metamorphic limestones of our own islands and Scandinavia, all traces of organic remains being often entirely gone.

CHAPTER XX.

CRETACEOUS PERIOD.

General Lie of Strata.—Turning back to Fig. 58, at p. 296, we see that the Purbeck beds pass under a considerable thickness of sands and clays called the Wealden beds. This succession may be observed in the Isle of Purbeck, either in Swanage Bay on the east side, or between Kimeridge Bay and Purbeck Hill on the west side of it. The beds here dip towards the north, and a considerable series of sands and clays come in one over another as we proceed in that direction, all finally plunging beneath a great mass of Chalk. This Chalk forms a prominent ridge striking due east and west, and terminating eastwards in a bold headland south of Studland Bay. Crossing, in the line of this ridge, to the Isle of Wight, we find a similar ridge of Chalk running through the middle of that island, making the headland of the Needles on the west and that of Culver Cliffs on the east. This Chalk also dips at a high angle to the north, and from underneath its lower beds the same series of sands and clays rise towards the south that appear south of the Chalk in the Isle of Purbeck. In both instances, after many

beds have cropped out to the south, the angle of inclination lessens, and the beds begin to flatten towards the south. In the Isle of Purbeck this does not take place until the Kimeridge Clay reaches the surface. In the Isle of Wight it takes place sooner, and the series above the Purbeck beds is probably thicker, so that none of the beds below the Wealden make their appearance.

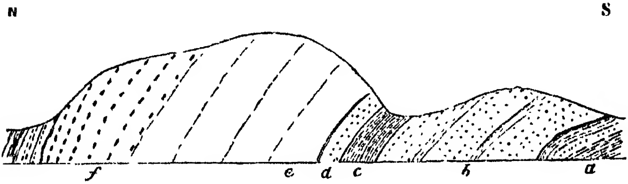

Fig 64.

Section through Shalcombe Down, on the west coast of the Isle of Wight.

		Feet.
h. London clay	Tertiary rocks	280
g. Plastic clay		
f. Chalk with flints		1200?
e. Chalk without flints		300?
d Upper Greensand		100
c. Gault		120
b. Lower Greensand		800
a. Wealden beds, exposed to a depth of		400

The section in Fig. 64 is a rough representation of the position of the series of beds on the west side of the Isle of Wight, the thickness assigned to the beds in the table being taken from the detailed sections and publications of the Geological Survey.

If, instead of following the Chalk ridge from the Isle of Purbeck into the Isle of Wight, we traced it back to Dorchester, we should find it turning off thence

towards the north-east up to Salisbury, and there expanding into the great undulating table-land called Salisbury Plain. To the northward of this the Chalk almost disappears in the valley of the Kennet, where it has been greatly eroded and is much concealed by beds above it. It becomes prominent again on the north side of this valley about Marlborough, and from that forms a continuous ridge of high swelling downs through Berkshire, Buckingham, and Hertford, the south of Cambridgeshire, and the borders of Suffolk and Norfolk, up to the great inlet of the Wash. Crossing this we find the Chalk ridge again in Lincolnshire, running about north by west to the Humber; and, crossing that estuary, we find it again in Yorkshire, where it makes the hills known as the Wolds, and terminates in the white broken cliffs of Flamborough Head.

This line of the Chalk escarpment, from Dorchester to the Yorkshire Wolds, runs parallel to the upper boundary of the Trias, mentioned in Chapter XVIII., and to the intervening ridge of the Oolites, the two ridges and the flats on each side of them forming persistent features all across England, from south-west to north-east, except for a small space north of the Humber, where the Chalk overlaps the Oolitic ridge and spreads across the upper beds, so as to rest upon the Lias. A similar and even greater overlap of the Chalk, and the Greensands below it, may also be observed in Dorsetshire, where they spread towards the west over the whole Oolitic series, and rest directly on Triassic rocks.

The Chalk escarpment runs directly into the sea at Flamborough Head; but on the coast of Dorsetshire, just before reaching the sea, it is suddenly deflected towards the east with a high northern dip and an east and west strike through the Isle of Purbeck and the Isle of Wight, as before described, running here almost at right angles to its main direction across England. If we return to the great expansion of the Chalk in Salisbury Plain, and follow that towards the east, we find that this expansion also forms an escarpment, but facing the east, near Alton and Petersfield, and that the very same sands and clays which rise from underneath the Chalk in the Isles of Wight and Purbeck also rise to the surface on the borders of Hampshire, Surrey, and Sussex, and spread through Sussex and Kent to the coast about Hastings, Rye, and Folkestone.

The re-appearance of these lower beds is due to the action of an anticlinal elevation over an east and west axis, which would have caused Salisbury Plain to be continued eastward as a broad ridge of Chalk, if it had not been for the subsequent erosion and removal of all the upper Cretaceous beds about the summit of the ridge. The piers or abutments of this arched ridge are still left in two long east and west lines of Chalk, the beds of which dip north and south respectively, while their ruined edges or escarpments face towards each other. The one forms the line of the South Downs, running from near Petersfield to Beachy Head, the beds of which dip south towards the English Channel; the other forms the ridge called the North Downs,

running past Farnham, Guildford, and Reigate, and terminating about Dover and Deal, its beds dipping to the north beneath the valley of the Thames.

The line of the London and Brighton Railway cuts directly across this eroded anticlinal arch, the lowest beds reaching the surface between Worth and Cuckfield, and being covered by the higher ones in each direction as they dip north and south from the centre or axis of the curve. Visiting first the Chalk hills north of Reigate, and then those 30 miles south of them, about Steyning and Lewes, or traversing the 50 miles that intervene between Beachy Head and Folkestone, and uniting in imagination the two escarpments that face towards each other by the sheets of Chalk that once spread between them, we get some idea of the magnitude of the erosive action that has removed such enormous masses of material. Great, however, as are the elevation and denudation that have been here effected, they really sink into insignificance compared with those that have acted on the Palæozoic rocks of the British Islands, the whole mass of which shows proof of greater disturbance and much more extensive denudation, the parts of them left in the ground being but the dislocated and ruined foundations of the great original formations.

Subdivisions of Period.—The Cretaceous rocks, whose distribution has been roughly sketched above, are separable into two great divisions:—1. The Lower or Neocomian; 2. The Upper or Chalk division. These include the following formations:—

			Feet.
Upper or Chalk Division.	7.	Maestricht Chalk	100
	6.	White Chalk .	1700
	5.	Upper Greensand	150
	4.	Gault . .	150
Neocomian Division.	3.	Lower Greensand	850
	2.	Weald Clay .	600
	1.	Hastings Sand	900

Neocomian Division.

The Neocomian rocks are so called from the Latinised name of Neuchatel in Switzerland. On the Continent they present a large series of marine beds separable into three groups, a Lower, Middle, and Upper Neocomian, with a thickness in some districts of 8000 feet. In England there are two different types of Neocomian rocks, those in the Yorkshire basin being wholly marine, and not much more than 500 feet thick, while in the southern districts there is a vast local development of fresh-water strata called the Wealden beds, surmounted by thick marine sands. These beds—viz. the Hastings Sand, Weald Clay, and Lower Greensand—have a general correspondence with the Lower, Middle, and Upper Neocomian of North England and the Continent.

Speeton Clay.—At Speeton Cliff in Yorkshire the Neocomian series is represented by a blue clay, which is very fossiliferous and divisible into three portions, the two upper of which extend southwards into Lincolnshire, limestones and sandstones becoming largely interbedded with the clays. The middle part of this Lincolnshire group is known as the Tealby series, and

is about 40 feet thick; it appears, however, to thin out towards the south of the county.

Wealden Beds.—That part of the counties of Sussex and Kent which lies between the Chalk ridges of the North and South Downs was formerly known as the Weald,* and hence the beds which now rise up to the surface over so large a part of it are known as the Wealden beds. These Wealden beds are usually grouped into two sets, the Hastings Sand below, and the Weald Clay above. The Hastings series consists of a series of sands and clays, with some bands of limestone, forming large partial cakes of deposit lying side by side and over each other, each thinning out from a point of maximum thickness until it dies away. Near Tunbridge Wells they have been classified by Mr. Drew under the following names:—

		Feet.
	Weald clay, *with an average thickness of* . .	600
4.	Tunbridge Wells Sand, *with clay beds* . . .	200
3.	Wadhurst Clay, *with limestone band* . . .	160
2.	Ashdown Sands, *with clays and ironstones* . .	510
1.	Ashburnham beds, *bottom not shown at* . .	330

In the later Memoir on the Weald by Mr. Topley, these names are retained, but the Ashburnham beds (only exposed over a small area north of Battle) are referred to the Purbeck series; one of the clays in the Ashdown group is signalised by the name of *Fairlight Clay.*

Although these beds attain an aggregate thickness

* Weald, or wold, means a wood, a forest, or wild uncultivated land, like the German "Wald."

of 1400 feet in the south-east corner of England, and have a respectable thickness near Boulogne, they have yet only a local character, never showing themselves from underneath the main Chalk escarpment about Dorchester or Marlborough, nor in any other part of its range across England. If it had not been, then, for the local elevation and denudation of the Chalk in the Wealden district, we should have known little of these beds. This local character, and the patchy nature of the several parts of it, taken together with the exclusively fresh-water or terrestrial origin of all the fossils it contains, induces the belief that the Wealden formation was nothing but a great delta formed at the mouth of some large river, which brought down the sweepings of a vast continent.

Lower Greensand.—In the Isle of Wight and in the Wealden country, the Weald Clay passes underneath some thick sands, sometimes forming a calcareous grit called Kentish rag, sometimes containing beds of clay and Fuller's earth. They have received the name of Greensand, from the frequent occurrence of beds containing small green grains, composed of a silicate of iron; these, according to Dr. Carpenter, are the casts of Foraminifera left by the removal of the shells (see p. 82), and are sometimes present in such numbers as to give a greenish hue to the sand. Their general colour is, however, dark brown or reddish, containing so much iron that they used to be called Iron-sands, and parts of them were formerly used as iron ore.

In Kent it consists of the following beds:—

	Feet.
4. Folkestone beds, with layers of calc-grit	90
3. Sandgate beds, greenish clayey sand . .	80
2. Hythe beds, Kentish Rag	60
1. Atherfield Clay, brown clay . . .	30

The thickness of the group at Atherfield, in the Isle of Wight, is 840 feet. It occurs over all the space occupied by the Wealden beds, and its upper members stretch beyond their limits through the counties of Oxford, Buckingham, Bedford, and Cambridge, until they are lost beneath the fens.

Neocomian Fossils.—Each division of the Speeton clay has its characteristic fossils, the large *Pecten cinctus*, *Ancyloceras Duvallii*, and *Belemnites jaculum*, may be cited as common in the Middle Division, and in the Tealby series. The Wealden beds contain fresh-water shells, both univalve and bivalve, together with plant remains and masses of fossil driftwood. The bands of limestone, commonly called Petworth or Sussex marble, are almost entirely composed of the shells of *Paludina fluviorum* and *Cyrena media*, both fresh-water molluscs. The most remarkable fossils, however, are the bones of large land saurian reptiles, first brought into notice by Dr. Mantell. The *Hylæosaurus* and *Iguanodon* were huge herbivorous reptiles 20 or 30

Pecten (*a comb*) cinctus (*a girdle*).
Ancyloceras (*curved horn*) Duvallii (*of Duval*).
Belemnites (*thunderbolt*) jaculum (*a dart*).
Paludina (*marsh shell*) fluviorum (*of rivers*).
Cyrena (*name of a nymph*) media (*common*).

feet long, the latter having teeth resembling those of the Iguana or tree lizard now living in tropical America. Their probable forms have become familiar to us from Mr. Waterhouse Hawkins's restorations in the garden of the Crystal Palace.

The fossils of the Lower Greensand are chiefly marine, most of them being quite peculiar to it; *Terebratula sella*, *Exogyra sinuata*, a kind of oyster, and *Gervillia anceps*, a shell related to *Avicula*, are three of the best known. It appears, then, that after the formation of the fresh-water Wealden beds, the whole neighbourhood must have been depressed beneath the sea, the waters of which spread over the land and its river-mouth, and buried the deposits of the latter under thick and widely spread accumulations of its own.

UPPER CRETACEOUS SERIES.

The Gault and Upper Greensand.—Above the Lower Greensand, almost wherever it occurs, a band of dark clay is found, known as the Gault, and over that some other sands, often very like the Lower Greensand, and therefore called the Upper Greensand. Calcareous grits occur in this, known as Malm rock or Firestone, and above this is a thin bed called the Chloritic Marl, with numerous concretionary nodules, which contain a large percentage of phosphate of lime,

Terebratula (*perforated shell*) sella (*like a chair*).
Exogyra (*curved outwards*) sinuata (*twisted*).
Gervillia (*from M. Gerville*) anceps (*doubtful*).

and form the so-called "Coprolites" used for manure; real coprolites, however, are fossil excrementa.

The true Upper Greensand does not extend farther north than Buckinghamshire; but in Bedfordshire and Cambridgeshire the base of the Chalk marl is formed by a thin seam of Greensand, resting unevenly upon the Gault below; this little bed is generally about 9 inches thick, and is full of black phosphate nodules. It has lately been shown that these "coprolites," including the greater part of the fossils found in the bed, have in all probability been derived from the Gault itself, the upper layers of that formation having been eroded and washed away during the time occupied by the deposition of the Upper Greensand and Chloritic Marl in the southern districts. The peculiar assemblage of fossils collected into this nodule bed is thus accounted for; it is usually called the *Cambridge Greensand*, but may be considered as homotaxial with the Chloritic Marl of the Isle of Wight. Farther north, in West Norfolk, the Gault also thins out and disappears, the Red Chalk or Hunstanton Limestone being the only representative of the Gault, Upper Greensand, and Chloritic Marl.

The Chalk.—The Chloritic Marl in the Isle of Wight and other places passes upwards into a marly Chalk, and then into pure Chalk. The marly beds are called the Chalk Marl, and are sometimes firm enough to be used as an interior building stone. The Chalk itself, of which the range in England has already been described, is divided into a Lower and Upper portion,

the latter abounding in layers of flints, while the Lower is destitute of them. Flints occur as lumps or nodules of all sizes, from that of a man's thumb up to one of a foot or two across, and of all kinds of fantastic shapes. These nodules generally lie parallel to the stratification, and flint also occurs sometimes in regular seams or layers at the bottoms of the beds, or sometimes in vertical veins along the joints. The silica, doubtless, owes its separation and concentration in the form of flints to the action of decomposing organisms, which have been the origin of so many other concretionary masses. Concretionary balls of iron pyrites, with a radiated internal structure, are also common in the Chalk. Near Norwich, in the boring of a well, flints were found in the Chalk for a depth of 800 feet without passing through into the Chalk without flints. In a boring near Harwich they found :—

	Feet.	Feet.
Chalk with flints	690	
Chalk without flints	160	
Chalk, rocky, in thin layers	38	949
Greensand and sandy Gault	22	
Gault without sand	39	

In a boring near Kentish-town, London, the following beds were passed through :—

		Feet.	Feet.
Tertiary.	London clay	236 0	
	Woolwich and Reading series	61 6	324 6
	Thanet sands	27 0	
ous.	Chalk with flints	244 6	
	Chalk without flints	294 0	
	Chalk marl	107 6	789 0
	Upper Greensand	12 6	
	Gault	130 6	

and form the so-called "Coprolites" used for manure; real coprolites, however, are fossil excrementa.

The true Upper Greensand does not extend farther north than Buckinghamshire; but in Bedfordshire and Cambridgeshire the base of the Chalk marl is formed by a thin seam of Greensand, resting unevenly upon the Gault below; this little bed is generally about 9 inches thick, and is full of black phosphate nodules. It has lately been shown that these "coprolites," including the greater part of the fossils found in the bed, have in all probability been derived from the Gault itself, the upper layers of that formation having been eroded and washed away during the time occupied by the deposition of the Upper Greensand and Chloritic Marl in the southern districts. The peculiar assem- [illegible]

through the Chalk beds into Carboniferous rocks, and even get coal in the latter. This shows us that the Palæozoic rocks extend under the more level Mesozoic beds, with the same highly inclined positions and greatly denuded surface which they have in the British Islands to the north-west of the New Red Sandstone plain, and which they also show in Belgium and the Rhineland.

Foreign Cretaceous Rocks.—Chalk, in its characteristic form, may, it is said, be traced here and there across Europe, from Antrim, where it is about 150 feet thick, with many characteristic fossils, into South Russia. In other parts of the world, however, the Cretaceous series consists, as we should expect, of very different materials. In the centre of North America

the latter abounding in layers of flints, while the Lower is destitute of them. Flints occur as lumps or nodules of all sizes, from that of a man's thumb up to one of a foot or two across, and of all kinds of fantastic shapes. These nodules generally lie parallel to the stratification, and flint also occurs sometimes in regular seams or layers at the bottoms of the beds, or sometimes in vertical veins along the joints. The silica, doubtless, owes its separation and concentration in the form of flints to the action of decomposing organisms, which have been the origin of so many other concretionary masses. Concretionary balls of iron pyrites, with a radiated internal structure, are also common in the Chalk. Near Norwich, in the boring of a well, flints were found in the Chalk for a depth of 800 feet with-

containing the old copper, lead, and iron mines of Laurium described by Strabo and Xenophon. The Marbles of Hymettus and Pentelicus, then, may be said to be nothing more than altered Chalk.

I mention these facts particularly, in order to point out that neither the kind of rock, nor the thickness of the deposits, in the stratified series of our own islands and western Europe, are to be taken as invariable guides. Here the Palæozoic groups only are of great thickness, or are ever altered into gneiss and mica-schist. Elsewhere the Secondary, and even the Tertiary, rocks form groups just as thick as our Palæozoic rocks, and are, or may be, just as perfectly converted into gneiss and mica-schist, and penetrated by granite.

In both these two latter cases, after passing through those beds, they came down into unknown rocks, probably of Palæozoic age, evidently passing an old surface of erosion on which the Cretaceous rocks rested unconformably.

It may be interesting to compare with these borings that for the Artesian well at Grenelle, near Paris, of which the following is an abstract, the depths being given in English feet.

	Feet.	Feet.	Feet
Superficial matters	16		
Plastic clay, etc.	167		
Chalk with flints	865	1271	1608
Chalk without flints	406		
Upper Greensand	183	337	
Gault	154		

In parts of France and Belgium they sink directly shells retaining all their pearly lustre and iridescent colours, such as are seen in the pearly interior of recent shells.

The Fossils in Fig. 65 are a few of those found in the Gault. *Trochocyathus conulus* is a coral. *Inoceramus sulcatus* and *Plicatula pectinoides* are conchiferous bivalves, the first belonging to an extinct genus, which did not survive the Cretaceous period, the latter being an extinct species of an existing genus. *Rostellaria* and *Scalaria Gaultina* are both extinct

Trochocyăthus (*trochus-cup*) conŭlus (*little c*
Inocerămus (*fibre vessel*) sulcatus (*grooved*).
Plicatŭla (*little fold*) pectinoides (*like a pect*
Rostellăria (*small beak*) carinata (*keeled*).
Scalaria (*staircase shell*) Gaultina (*of the Ga*

they are chiefly sands and clays, with some good beds of bituminous coal six feet thick. In the Andes of South America vast masses of dark clay-slate, just like those found in our Silurian formations, together with brown argillaceous limestones, masses of red sandstone, with gypseous deposits, having a total thickness of 7000 or 8000 feet, are described by Mr. Darwin as running from Columbia north of the Equator into Tierra del Fuego, having Cretaceous fossils in some parts, and in other beds fossils more like Oolitic ones.

In Greece the Hippurite limestone, answering to our Chalk, is associated with red marls and sandstones, all becoming converted towards the east into talc-schists, mica-schists, and crystalline limestones, like those of Donegal and the Highlands of Scotland, and

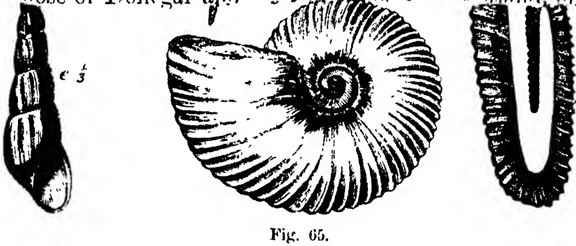

Fig. 65.
Gault Fossils.

a. Trochocyathus conulus.
b. Inoceramus sulcatus.
c. Plicatula pectinoides.
d. Rostellaria carinata.
e. Scalaria Gaultina.
f. Bellerophina minuta.
g. Ammonites splendens.
h. Hamites attenuatus.

animal like the much larger Bellerophon of the Carboniferous period. *Ammonites splendens* is another

Bellerophina (*little Bellerophon*) minūta (*minute*).
Ammonites (*ram's-horn shell*) splendens (*glistening*).

These are all local accidents, and not essential characters of any part of the series.

Maestricht Chalk.—The English Secondary series closes with the Chalk. In the North of France, about Maestricht in Holland, and in Denmark, there are on the true Chalk certain beds of yellowish or whitish chalky limestone, pisolitic in France, which contain, with many characteristic Chalk fossils, others which are specifically peculiar to those beds, but belong to genera that are elsewhere found only in Tertiary rocks. It was in these that the head of the large lacertilian reptile Mosasaurus Hofmanni was found at Maestricht, the head being three feet in length.

Cretaceous Fossils.—The fossils of the Gault are often most beautifully preserved, even the most delicate *æqualis*, *Turrilites costatus*, and *Baculites anceps*, are, like the Hamite mentioned above, curious modifications of the Ammonite family, in which the shell, still chambered with indented and frilled partitions, is bent at both ends so as to resemble a boat in the Scaphite, to assume a turreted form in the Turrilite, while in the Baculite the spiral shell is completely unrolled and pulled straight like a stick. The Baculite, then, was to

Hamites (*hook fossil*) attenuātus (*thinning out*).
Rhynchonella (*little beak*) Cuviĕri (*of Cuvier*).
Inocerămus (*fibre vessel*) mytiloides (*mussel-like*).
Lima (*file shell*) Hopĕri (*of Hoper*).
Ammonites (*ram's-horn shell*) varians (*varying*).
Scaphites (*skiff shell*) æquālis (*equal*).
Turrilites (*little tower*) costatus (*ribbed*).
Băcŭlites (*staff-shell*) anceps (*doubtful*).

species of still existing genera of Gasteropoda. *Bellerophina minuta* was possibly a shell of a pteropodous

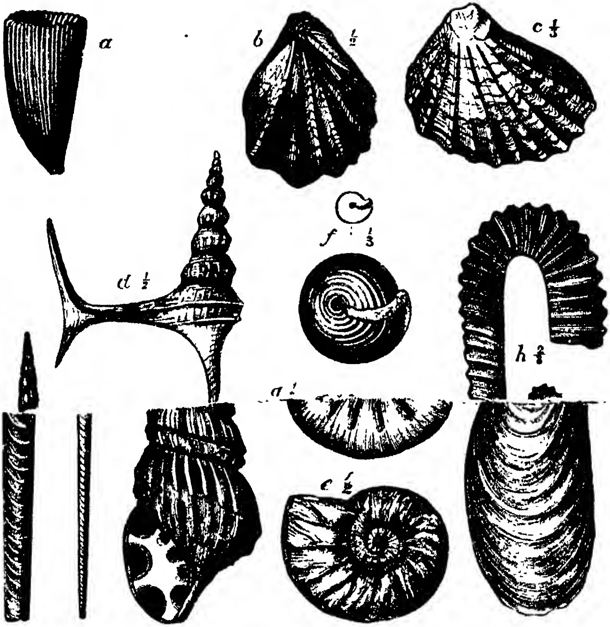

Fig. 66.

Chalk Fossils.

a. Holaster subglobosus.
b. Rhynchonella Cuvieri.
c. Inoceramus mytiloides.
d. Lima Hoperi.
e. Ammonites varians.
f. Baculites anceps.
g. Scaphites æqualis
h. Turrilites costatus.

The Chalk abounds also in Echinodermata, especially in the Echinoidea or Urchin family, which now begins to assume the superiority in numbers over the Crinoid

or Lily family, which it has ever since maintained. *Holaster subglobosus* is confined to the Lower Chalk; while others, called *Galerites albogalerus*, *Micraster coranguinum*, and *Ananchytes ovatus*, are characteristic of the Upper Chalk. These genera seem not to have existed either before or after the Cretaceous period, and are therefore good evidence that any deposits containing them were formed during that time.

Many large and curious bodies are found in the Chalk which were allied to Sponges; these are often enveloped in flint; and in fact almost all flints, when examined under the microscope, show traces of sponge structure and of the siliceous spicules which were scattered through their substance.

In the Cretaceous rocks of the south of Europe there are found a number of curious coarse bivalve shells, forming a peculiar family called the Rudistæ; one of them is called *Hippurites*, and some calcareous beds are called Hippurite limestone in consequence. So rude and rough are the form and structure of these shells that they have been mistaken for Corals. These shells, and the genus *Inoceramus*, seem to be peculiarly characteristic of strata referred to the Cretaceous series in different parts of the world. In England, however, the Rudistæ are almost confined to the Cambridge

Hŏlaster (*whole-star*) subglobosus (*roundish*).
Galĕrites (*bonnet-shell*) albogălĕrus (*white bonnet*).
Micraster (*small star*) coranguĭnum (*snake's-heart*).
Ananchȳtes (*unsqueezed shell*) ovātus (*egg-shaped*).

Greensand and Chalk Marl, where they are represented by the genus *Radiolites*.

Crustacea also abound in many parts of the Cretaceous series, and beautiful specimens of Fish occur, especially in the true Chalk, in which their glistening brown scales and sharp polished teeth form conspicuous objects. Many of the genera of Reptiles which existed during the Oolitic period survived into the Cretaceous; bones of the *Megalosaurus* having been found in the Wealden beds, and peculiar species of *Ichthyosaurus*, *Plesiosaurus*, and *Pterodactylus*, in different members of the Cretaceous series, up to the true Chalk. Professor Owen tells us that the bones of the three species of Pterodactyles from the Greensand of Cambridge (*P. Fittoni*, *P. Sedgwickii*, and *P. simus*) are so large as to indicate that the animal had a spread of wing amounting to 18 or 20 feet; and two others from the Chalk of Kent were little inferior in size. There were also many other genera of reptiles belonging to other orders of the class, some of them much more near to true Lizards, of which the great *Mosasaurus* (*Lizard of the Meuse*) is an example.

A bone of a true Bird was also found by the late Mr. Lucas Barrett in the Cambridge Greensand or Nodule bed, and several have been found since, belonging to two birds which were probably allied to the gull tribe. No mammalian remains have been found as yet in the Wealden deposits, nor in any part of the Cretaceous series, although they doubtless existed on the dry lands during the whole time.

CHAPTER XXI.

TERTIARY OR CAINOZOIC EPOCH.

SIR C. LYELL proposed for the division of this epoch into periods a more systematic nomenclature than that which has been used for the preceding periods. As we trace the stratigraphic series from older to newer deposits, the fossil organic forms become gradually more like those which now live. No fossils, however, have been found in any Palæozoic or Mesozoic deposit specifically identical with any now existing, except perhaps some Foraminifera, one of the lowest forms of animal life, the species of which it is difficult to determine with accuracy. It is in the Cainozoic or Tertiary rocks that we first find a fossil organism identical with a living one. This identity of species, however, does not reach higher than the Mollusca until we arrive at the most recent of all deposits; for, except in them, no fossil Fish, Reptile, Bird, or Mammal, has ever been identified with a living one. Looking chiefly to the shells of the Mollusca, therefore, Lyell's principle of classification refers to the proportion of species among the fossils that can be identified with existing forms, compared with those that are manifestly extinct. Taking the Greek word καινὸς (kainos, usually anglicised

as cæno or ceno, and meaning *new*) as referring to these new or recent species, he combines it with ἠὼς (eos, *the dawn*), μείων (meion, *less*), πλείον (pleion, *more*), πλεῖστος (pleistos, *most*), to make names for the four periods into which the Tertiary Epoch is divisible. Eocene then means the period in which recent, or still existing, species of Mollusca first dawned upon the earth.

Eocene Period.

The fossil shells of the Eocene period are supposed to contain not more than five per cent of still existing species, and it may be doubted whether the earlier beds contain any. Of the British Eocene fossil shells none are now living in any European seas.

The division between the Secondary and Tertiary Epochs, like that between the Primary and Secondary, is based on the existence of a great gap or break in the series. After the close of the Cretaceous period there seems to have been a time rather of destruction than of production over most of the European area; and the rocks that were deposited during this time in other parts of the world are not yet known to us.

In England Mr. Prestwich is of opinion that the anticlinal arch over the Wealden area had been formed, and the Chalk greatly eroded, so that in some places the Greensands below the Chalk had been laid bare before even the lowest of the Eocene beds was deposited. It does not follow that any of the valleys which now traverse the Wealden district and the adjacent Chalk escarp-

ments had been excavated. The Cretaceous beds may have been cut off by erosion above in such a way as that the surface may have always been a plain or very low ridge, and the tilting of the Chalk may have been so slight that when the Eocene deposits were formed on it, they may have been apparently parallel to it. Further disturbance and denudation have certainly taken place since, both in the Wealden area and along the line running through the Isle of Wight, so as to tilt the Eocene beds themselves, as well as the Chalk, into a vertical or highly inclined position, as shown in the following section.

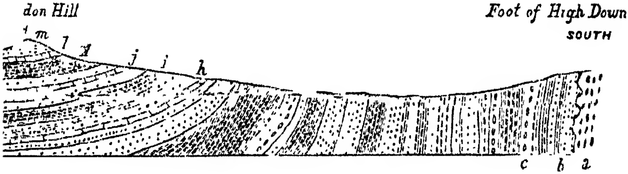

Fig. 67.

Section on west side of Isle of Wight—length about 700 yards.

		Feet.			Feet.
m.	High level gravel.		*f.*	Barton clay	300
l.	Bembridge beds	25	*e.*	Bracklesham beds	110
k.	Osborne beds.	50	*d*	Lower Bagshot sands . . .	660
j.	Upper Headon beds . .	85	*c.*	London clay	200
i.	Middle Headon Beds . .	30	*b.*	Plastic clay and sands = Woolwich and Reading beds . .	140
h.	Lower Headon beds . .	65	*a.*	Chalk, with eroded surface .	
g.	Upper Bagshot sands . .	120			

Note.—There is a little mistake in this woodcut in the lines of *f*, which are made to end against the base of *g*, instead of running parallel to it. This gives the appearance of an unconformity which does not exist. The whole of the Eocene beds are parallel and conformable to each other.

This section is the most complete one of any Tertiary rocks shown in any one locality in the British

Islands, being only deficient in the lowest group of all, which lies below the Plastic Clay in the London basin, but does not exist in Hampshire. The London Clay itself also is much thicker under London than in Hampshire, being nearly 500 feet in Sheppey.

The following table will give an abstract of the whole of the English Eocene series, combining the beds found in the London basin with those of the Isle of Wight:—

EOCENE FORMATION.	*Groups.*	*Sub-Groups.*		
Upper.	Bembridge series.	*b.* Marls and oyster beds	90	
		a. Limestone . .	25—	115
	Osborne series	*b.* St. Helen's Sands .	50	
		a. Nettlestone grits .	20—	70
	Headon series	*c.* Upper fresh-water .	85	
		b. Middle marine . .	50	
		a. Lower fresh-water .	65—	200
Middle.	Bagshot series.	*d.* Upper sands . .	200	
		c. Barton clay . .	300	
		b. Bracklesham beds .	110	
		a. Lower sands and clays	660—	1270
Lower.	London series.	*d.* London clay . .	480	
		c. Oldhaven beds . .	40	
		b. Woolwich beds, in London basin 90 feet, in I. W.	140	
		a. Thanet sands . .	90—	750
		Feet .		2405

The *Thanet Sand* is a light-coloured sand which attains its maximum thickness in the Isle of Thanet, stretches past Woolwich and London, and dies away near Reading.

The *Plastic Clay* or Woolwich and Reading series is

a variable mixture of clays, sands, and gravels, which is not more than 30 feet thick at Herne Bay, but thickens towards the west, while the corresponding beds in the Isle of Wight are still thicker.

The *Oldhaven beds* consist mainly of flint shingle and sands, and are usually from 20 to 40 feet thick; they were originally classed as a subordinate division of the London Clay, but are now treated as the uppermost member of the Lower London Tertiaries.

The *London Clay* is a dark unctuous clay, which is thickest about the Isle of Sheppey, and gets thinner towards the west, but seems to have thinned out altogether to the east of the British Islands, as it is scarcely represented in Belgium, and not at all in France.

The *Lower Bagshot Sands* cap Hampstead and Highgate Hills, and spread over the heaths of Bagshot, Aldershot, and the adjacent country. These are the highest Eocene beds which have been left in the flat open basin of the Thames, and they consist mainly of unfossiliferous sands.*

The higher beds are only found in the Hampshire basin, where they have been protected from subsequent denudation by being tilted up at a high angle into a deeper basin, and thus made to dip beneath the present surface of the ground. Here above the Lower Bagshot Sands we find the *Bracklesham beds*, consisting of dark-coloured marls and clays in the lower part, with white

* For a compendious sketch of the strata comprised in the London Basin, see the "*Guide to the Geology of London*," by W. Whitaker—Price one shilling.

and green sands above. The *Barton beds* are next in succession, consisting mainly of greenish sandy clays full of fossils; and the series is completed by the pale sands and clays of the *Upper Bagshot beds.*

The *Headon group* comprises a succession of clays, marls, sands, and fresh-water limestones, the last being almost made up of shells belonging to species of *Limnæa* and *Planorbis.* The *Osborne* and *Bembridge groups* are also made up of fluviomarine limestones, marls, and sands; they spread over a large portion of the northern half of the Isle of Wight, but never attain any great thickness.

The Chalk and other Cretaceous rocks of England, beyond the shallow notch which the sea has worn in them to form the Straits of Dover, spread in gentle undulations through the greater part of the North of France. The Eocene beds there rest upon the eroded surface of the Cretaceous rocks, and when the chalk sinks into a basin-shaped depression round Paris, we find the whole Eocene series lying in the hollow. The Woolwich and Reading beds are represented in France by beds very similar to the English ones, our term of Plastic clay being indeed but the translation of the original French designation of *Argile plastique* assigned to those beds by the early French geologists. The Thanet sands below them are scarcely if at all represented in France, while the London Clay above is altogether absent. The Lower Bagshot sands are represented by shelly and sandy beds while the Bracklesham beds are believed to be contem-

poraneous with the coarse limestone or *Calcaire Grossier*, which is the building-stone so much used in Paris. Other sands above this are believed to be the representatives of the Barton clay and the Upper Bagshot sands, while beds called the Beauchamp grit (*Grès de Beauchamp*) and Marine limestone (*Calcaire marin*) are considered equivalent to the Headon and Osborne series. Above these come the gypsum beds so largely quarried near Montmartre, which, with the fresh-water limestone (*Calcaire lacustre*) and siliceous limestone (*Calcaire siliceux*), are correlated with the Bembridge series of the Isle of Wight.

Over these come the *Fontainebleau* sands and grits, and the fresh-water limestone called the *Calcaire de la Beauce*, which seem to overlap the lower beds and spread far beyond them over the edges of the Cretaceous strata, resting unconformably upon any lower rocks. These deposits many French geologists class as Miocene, and Sir C. Lyell also adopts this view, considering the Hempstead beds of the Isle of Wight as their probable representatives (see p. 351).

Life of the Period.—The general statements as to the distribution of the fossils in the Oolitic formation made in Chapter XIX. would equally apply to those of the Eocene. Each series or group, and each sub-group, mentioned in the table on p. 337, has a peculiar assemblage of fossils belonging to it. Some of these species do not occur anywhere else except in the little sub-group, others range through all the sub-groups of a series, and others again—but these very few compared with the

whole assemblage—are found in two or even three of the groups. These common fossils serve to link the groups together into larger divisions, called in the table Upper, Middle, and Lower Eocene.

Most of the Eocene beds are crowded with beautiful fossil shells and other animal remains, and in some places with the fruits and leaves of plants.

A great number of these fruits, converted into iron pyrites, were formerly procured from the London Clay in part of the Isle of Sheppey. Some of them resembled coffee berries, and others the nuts of palms. A few Corals and Polyzoa, one or two Brachiopoda, many ordinary bivalve and univalve shells, a splendid Nautilus and other Cephalopoda, some starfishes and other Echinodermata, several Crustacea resembling the lobsters and crabs of the present time, some Fish and Reptiles, including the Turtles, Crocodiles, and Snakes, two species of Birds, and several of Mammalia, have also been procured from the London Clay.

In the group of fossils given in Fig. 68 we have a few species of Lower Eocene fossils figured. *Terebratulina striatula* was a species of a still existing genus of Brachiopoda. *Pinna affinis*, *Cyrena cuneiformis*, and *Cryptodon angulatum*, were Conchifera or ordinary bivalves—all being extinct species of existing genera.

Terebratulīna (*little terebratula*) striătŭla (*striated*).
Pinna (*wing shell*) affīnis (*kindred*).
Cyrēna (*prop. name*) cunĕĭformis (*wedge-shaped*).
Cryptŏdon (*hidden-tooth*) angulatum (*angled*).
Volūta (*twisted shell*) Wetherellii (*of Wetherell*).

Voluta Wetherellii and *Aporrhais Sowerbii* are extinct species of existing genera of Gasteropoda, and *Nautilus*

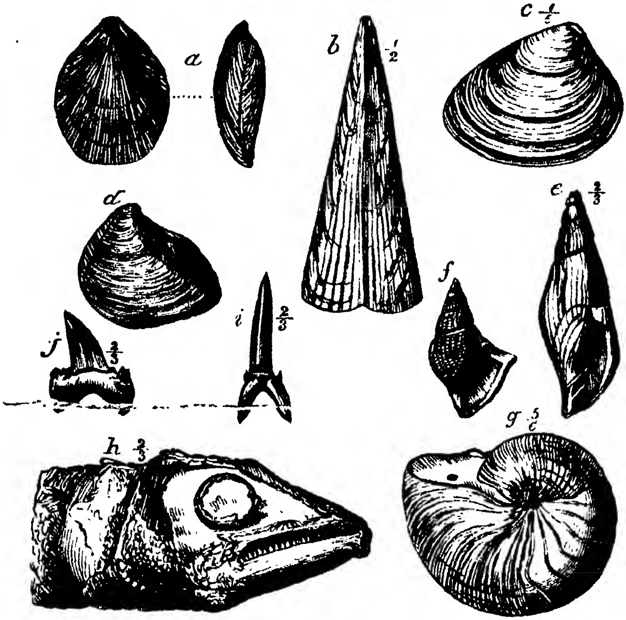

Fig. 68.

Lower Eocene Fossils.

a. Terebratulina striatula. *d*. Cryptodon angulatum. *g*. Nautilus imperialis.
b. Pinna affinis. *e*. Voluta Wetherellii. *h*. Coelopoma Colei.
c. Cyrena cuneiformis. *f* Aporrhais Sowerbii. *i*. Lamna elegans.
j. Otodus obliquus.

imperialis another extinct species of the persistent

Aporrhāis (*destroyer*) Sowerbii (*of Sowerby*).
Nautĭlus (*little sailor*) imperiālis (*imperial*).

cephalopodous genus Nautilus. *Otodus obliquus* and *Lamna elegans* were extinct species of Sharks, while *Cœlopoma Colei* belonged to another order of fish.

Passing from the Lower to the Middle Eocenes, we find still the same, or even a greater richness of fossils—the clays of the Barton and Bracklesham beds especially being in parts of the coast of Dorsetshire and Sussex absolutely full of shells, which may be cut out with a knife in as perfect a state of preservation as when they were living in the waters.

It is in the Bracklesham beds that we first meet in Britain with the remarkable Foraminiferal shell, the *Nummulite* (Fig. 69 *b*), which is so abundant in the Eocene rocks of the countries bordering on the Mediterranean, and stretching thence through Asia along the south flank of the Himmalayah mountains, as to make up great beds of limestone, with an aggregate thickness of many hundreds, if not thousands, of feet. These Nummulite beds are found contorted in the mountains of the Alps, and raised to a height of 16,000 feet above the sea in Thibet. The Great Pyramid of Egypt is built of this stone.

Fig. 69 *a* is a kind of coral called *Litharæa Websteri;* the *Conus*, *Fusus* and *Murex* belonged to co-existing genera of Gasteropoda, and the rest belong to various genera of bivalve shells. Besides these and

Otŏdus (*ear-tooth*) obliquus (*oblique*).
Lamna (*a blade*) elegans (*graceful*).
Cœlopōma (*hollow-lid*) Colei (*of Lord Cole*).

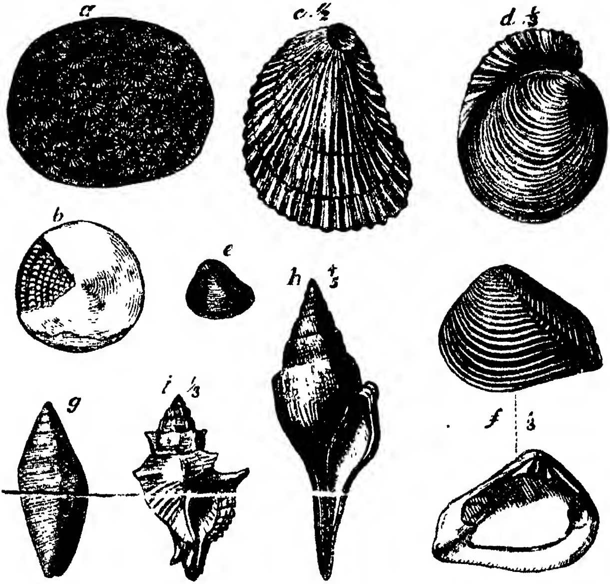

Fig. 69.

Middle Eocene Fossils.

Litharæa Websteri.	*d*. Chama squamosa.	*g*. Conus dormitor.
Nummulites lævigatus.	*e*. Corbula pisum.	*h*. Fusus longævus.
Ostræa flabellula.	*f*. Crassatella sulcata.	*i*. Murex asper.

Murex (*Latin name of shell*) asper
Crassatella (*thick-shell*) sulcata (*gr*
Chama (*gape-shell*) squamōsa (*scal*
Corbŭla (*little basket*) pisum (*a pea*
Conus (*cone-shell*) dormītor (*a slee*
Ostræa (*an oyster*) flabellŭla

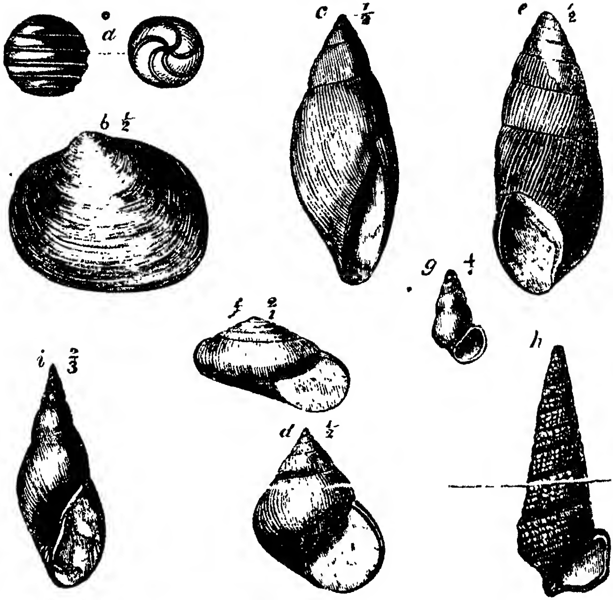

Fig. 76.

Upper Eocene Fossils.

a. Chara medicaginula.
b Cyrena pulchra.
c. Achatina costellata.
d. Paludina orbicularis.
e. Bulimus ellipticus.
f. Helix D'Urbani.
g. Hydrobia Chastel
h. Cerithium elegans
i. Limnæa longiscat

Chara (*? wild cabbage*) medicaginŭla (*medicinal ?*)
Cyrēna (*proper name*) pulchra (*beautiful*).
Achatīna (*Agate-shell*) costellāta (*finely-ribbed*).
Paludīna (*marsh-shell*) orbicŭlāris (*orbicular*).
Bulīmus (*very hungry*) ellipticus (*elliptical*).
Helix (*coil-shell*) D'Urbāni (*of D'Urban*).
Hydrōbia (*living in water*) Chastellii (*of Chastell*).
Cerithium (*a little horn*) elegans (*graceful*).
Limnæa (*lake-shell*) longiscata (*elongated ?*).

other shells, the remains of Fish, Reptiles, and Mammalia occur in Middle Eocene beds.

In the Upper Eocene, as we lose the marine deposits, we no longer get the great variety of marine shells and other animals, though the few species of land and fresh-water shells that do occur are often in immense abundance. Some of these are figured in the fossil group Fig. 70. Of these, Fig *a* is the seed-vessel of the *Chara medicaginula*, a fresh-water plant which secretes carbonate of lime; the *Cyrena pulchra* is another extinct species of that genus, while the rest are all extinct species of well-known existing genera of land and fresh-water snails, except *Hydrobia** and *Cerithium*, which are brackish water genera.

Along with these, the remains of fourteen species, belonging to eight extinct genera, of land Mammalia have also been found in the Isle of Wight in the Upper Eocene beds, which, with four other genera from the Middle, and four or five more from the Lower Eocene, make sixteen or seventeen genera found in the British Islands.

The Mammals found in the Lower Eocene beds, and described by Professor Owen, were the *Coryphodon*, a tapir-like animal, twice as large as the American tapir, and lesser animals called *Hyracotherium* and *Pliolophus*, which were more nearly allied to the Hog tribe. The *Didelphys Colchesteri* was a marsupial

Cŏrўphŏdon (*crest tooth*). Pliolophus (*nearer ridge*).
Hyracothĕrium (*Hyrax beast*). Didelphys (*two wombs*).

* *Hydrobia Chastellii* is a Hempstead or Miocene species.

animal of the earlier part of the period, belonging to the same genus as the existing American opossums.

In the British Middle Eocene beds the remains of species of animals called *Dichodon*, *Lophiodon*, *Microchœrus*, and *Paloplotherium*, have been found. The three first were small animals, having some affinity with the Chevrotanes or Musk animals of the East, which are placed by Cuvier between the Camels and the Deer.

In the Upper Eocene of the Isle of Wight fragments of many of the same animals as those from the gypsum beds of Montmartre have been discovered. The most remarkable of these are the genera *Palæotherium*, intermediate between the rhinoceros, the horse, and the tapir, of which eleven or twelve species are known, varying in size from a pig to a horse or rhinoceros; *Anoplotherium*, in one respect between a horse and a rhinoceros, but having affinities with the hippopotamus, the hog, and the camel, of which five species are known, varying in size from a hare to an ass, the largest having a long and strong otter-like tail, as if to assist it in swimming; *Chœropotamus* was an animal of the Hog tribe.

Most of these fell into Cuvier's order of Pachydermata (*thick skins*), in which he included the Elephant and Rhinoceros, the Horse, the Hippopotamus, and the

Dichŏdon (*split-tooth*). Paloplothērium (*old armed beast*).
Lophiŏdon (*ridge-tooth*). Palæothērium (*ancient beast*).
Microchœrus (*little pig*). Anoplothērium (*defenceless beast*).
Chœropotamus (*river hog*).

Hog, but which Huxley divides into three orders—Proboscidea, Ungulata, and Hyracoidea. Many of them seem to have been adapted for living on rich marshy plains on the borders of rivers and lakes. There were, however, Carnivora adapted to prey upon these animals, one of them called *Hyænodon*, apparently more fell and deadly than our modern wolves and tigers, if we can judge by the size and shape of its teeth.

Numerous, however, as are the genera of the Mammalia found in the Eocene rocks of England, they are exceeded by those of France.

It was from the gypsum beds of Montmartre that Cuvier procured most of the remains of mammalian animals, from the study of which he may almost be said to have founded the science of comparative anatomy, and astounded the scientific world of his contemporaries with his extraordinary discoveries. It seems at first impossible that any one should, from the examination of a piece of an animal, of which neither he nor any other man ever saw any more than that fragment, be able to tell us what kind of an animal it was, and what were its habits and even its general form. The principle on which this can be done, however, is intelligible enough, although the skill and sagacity required, either to discover it in the first instance, or even to apply it now without error, may be as rare as admirable. Every ploughboy knows the difference between a cow's tooth and a horse's, and most would tell you at once which belonged to a sheep and which to a pig. No one who was shown

Hyænodon (*hyæna-tooth*).

the skull of a lion could imagine that it belonged to a deer or an antelope ; the great conical fangs and sharp-pointed teeth would show at once that they were intended to tear flesh, and not to nibble grass or to grind grain. But the jaws intended to seize and tear, and therefore to work vertically, must obviously have a different sort of insertion into each other from those intended to grind, and therefore to move horizontally. By the study, then, of the different kinds of insertions of the jaws, a man might learn to distinguish between carnivorous and herbivorous animals, as well as by looking at their teeth. Moreover, an animal which has to live by leaping on its prey, and holding it with claws, must have feet or paws armed with sharp nails or talons, defended by soft pads underneath to protect the paws from the shock should it alight on the ground, and the shape of its leg bones, and the bones answering to our wrists or ankles, must be all adjusted accordingly, and the muscles must also be adapted to the work, and therefore the insertions of those muscles, or the knobs and ridges of the bones to which they are attached. An animal with the head of a tiger and the feet of a deer or a sheep must inevitably starve to death. The form of the teeth then involves a certain form in the extremities, and in the shape of all the bones of which those extremities are made up. By studying all these modifications in living animals, and learning their application to the habits and necessities of the animals, it is clear that we might be able to determine from the bones of the extremities whether the animal

had talons or hoofs, and whether therefore it were carnivorous or herbivorous, even if it were the bones of an animal we had never seen before.

The skeleton of each animal is, in fact, a perfect piece of machinery, the object of which can be discerned from the study of its structure, and each one of its parts is so clearly and definitely adapted to all the rest that no one could be altered in shape or size without either carrying out a corresponding alteration throughout the details of its structure or vitiating the whole machine. A man profoundly versed in the knowledge of such machinery, and skilled in tracing the uses of its several parts, will obviously be able to detect the meaning of the modifications observable in the parts of a similar machine that is new to him, and follow to their legitimate conclusions all the consequences of these modifications. In other words, a good comparative anatomist, if he find a critical bone or tooth of a new animal, will be able to give a very close approximation to the shape, size, habits, and appearance of that animal.

Cuvier even predicted, from a few fragments, peculiar structures in the skeletons, which were afterwards found to exist when more perfect specimens of the fossils were discovered.

It must be borne in mind that, although these discoveries appear more striking to us when they relate to that highest class of animals to which we ourselves belong, the principles just now sketched out are applicable to all the classes of the Animal Kingdom, down even to the lowest.

CHAPTER XXII.

MIOCENE PERIOD.

THE proportion of existing species found among the fossil shells of the Miocene period may, according to Sir C. Lyell, be taken at about 20 or 30 per cent, the recent species being still in a *minority*. Few deposits in the British Islands can be with any certainty assigned to the Miocene Period.

Hempstead Beds.—At Hempstead near Yarmouth, in the Isle of Wight, the Bembridge beds are covered by a series of marls and clays, formerly classed with the Eocene series, but now, in accordance with Sir C. Lyell's views, more generally considered Lower Miocene. They are evidently passage beds, and the succession of strata is as follows :—

	Feet.
4. Corbula beds	15
3. Upper estuary and fresh-water marls . .	40
2. Middle ,, ,, ,, . .	50
1. Lower ,, ,, ,, . .	65
	170

The most important fossils are *Voluta Rathieri*, *Cerithium elegans* (Fig. 70 *h*), *Hydrobia Chastellii* (Fig. 70 *g*), *Cyrena semistriata*, and *Corbula pisum* (Fig. 69 *c*).

In the lower beds are found bones of the mammal *Hyopotamus bovinus*.

Bovey Tracey.—Near a place of this name in Devonshire there is a little basin containing 300 feet of clays, sands, and lignites, which have evidently filled up an ancient hollow or lake during the Lower Miocene Period, for they enclose numerous remains of ferns, shrubs, and trees, many of which, when examined by the Swiss botanist M. Heer, were found to be the same as those in the Lower Miocene of Germany and Switzerland.

Inner Hebrides.—In the Islands of Mull, Skye, and Staffa, there are a series of volcanic rocks, more than 3000 feet thick, which Professor Geikie has lately shown to date from the Miocene Period; interstratified h them in some places are regular beds of coal, and at Ardtun in the Isle of Mull several layers of tuff and clay occur. These were first brought into notice by the Duke of Argyle, as containing plant-remains similar to those found in continental Miocene beds.

Ireland.—Similar volcanic rocks extend into the North of Ireland, and form the great basaltic plateau of Antrim, one small bed of which makes the well-known Giant's Causeway. Here also the old lava-streams are interstratified with beds of ash containing layers of lignite, and in one case the leaves of trees; the formation spreads over the Chalk throughout an area of 1200 square miles, with an average thickness of 500 feet. The section, Fig. 71, shows how these rocks occur; the Chalk is hardened and baked, and between its eroded

surface and the basalt a bed of clay full of burnt flints always occurs.

This section shows us that the Carboniferous rocks rest upon an old eroded surface of Lower Silurian, and have themselves been contorted and denuded, so as to form an eroded surface on which the Secondary rocks lie. We also see that although there was a considerable deposition of beds during the New Red Sandstone

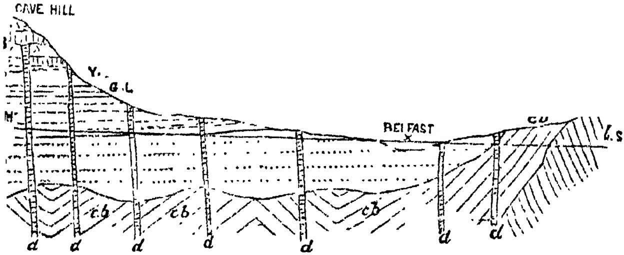

Fig. 71.

Diagrammatic section across Belfast Valley.

	Feet.		Feet
B. Basalt flows . . .	up to 900	*N. R M.* Triassic marls	600
C. Chalk, with eroded surface = *Y*	up to 250	*N. R. S.* Triassic sandstone	600
G. Greensand	25	*c b.* Carboniferous rocks.	
L. Lias	30	*l. s* Lower Silurian rocks.	
d. Dykes of basalt.		× Clay and silt in Belfast Lough.	

period, there is, after a few of the bottom beds of the Lias had been formed, an entire absence of all the great Oolitic and Lower Cretaceous series, and that the Chalk itself is but very imperfectly represented. The Chalk, however, was evidently once thicker, perhaps a good deal thicker than it is now, and it might possibly have been altogether removed by the denuding action, if it had

not been covered, during the Miocene period, by its great capping of lavas and ash-beds. These igneous rocks also spread originally over a wider area than they do now, as is shown by their abrupt termination in cliffs and precipices all round, as well as by the extension of the dykes which were their feeders through much of the country outside their area. The strata above described point unmistakably to the existence of land over the British Isles, and consequently the lava streams from its volcanoes, and a few fluviatile and lacustrine deposits are the only evidence of a period marked by the formation of thick beds in other parts of Europe. It is to this period also that disturbances evinced by the Cretaceous and Eocene strata were probably due.

Foreign Deposits.—On the continent of Europe, many widely spread beds in Belgium and France have been classed as Miocene by Sir C. Lyell and others, especially those called the Faluns of Touraine and the great lake formations of Auvergne, which now form hills several hundred feet in height.

Volcanic activity showed itself in France probably in early Miocene times, for the great volcanic masses of the Mont Dor and the Cantal seem to have been formed before the deposition of many of the fresh-water beds, but it was continued through the Upper Miocene and even into Pliocene and Post-Pliocene times; many of the volcanoes of the Puy de Dome district, and some of those in the Velay country, being as fresh-looking as if they had been just ejected.

The beds around Vienna, and those about Mayence

in the basin of the Rhine, and part at least of the great series of sands and clays and gravels and conglomerates known as the Molasse, belong to this period.

In the central lake country of Switzerland, lying between the Jura and the Alps, many mountains are composed of these beds, a single mass of conglomerate called Nagelflue being reckoned at 6000 feet thick. The Rigi, which is chiefly composed of it, rises to 5905 feet above the sea, and more than 4000 above the Lake of Lucerne, at its foot.

Miocene beds have even been found in the Arctic Regions, and a large number of plants have been collected from them in various parts of Greenland, Iceland and Spitzbergen. Many of these are trees,—beeches, oaks, planes and poplars,—indicating a climate very much warmer than that now prevailing over the same area; it is remarkable also that many of the species are identical with those found in the above-mentioned Miocene beds of Central Europe.

In India the beds which make the Sewalik Hills, a range of very considerable altitude running along the foot of the Himmalayahs, are believed to be Miocene.

Miocene Fossils.—Many of the European beds are crowded with fossil shells, of which about 25 per cent are generally found to be of existing species. The Mollusca inhabiting the European seas seem to date their origin from this period, so far as species are concerned.

Among Mammalia several existing orders or genera have the same date. The Deer tribe, the Proboscidean animals, the Rhinoceros, and the first approach to the

Hippopotamus and the Horse, may be reckoned among these; and the Monkeys also were now certainly in existence. The Proboscidean animals had three well-marked genera during this period—the *Elephants*, of which there are two now existing species; the *Mastodon*, a rough-toothed elephant, which became extinct at a much later period; and the *Deinotherium*, which did not survive the Miocene period. The Deinotherium seems to have been a kind of water elephant with a short proboscis and two down-curved tusks, which proceeded from the lower jaw instead of the upper as in the Elephants. One species of Deinotherium has been found in Europe and another in India. Many of the animals found in these Miocene deposits form intermediate links between those of the Eocene period and existing species, as is shown by Professor Owen in his Palæontology. "The *Deinotherium* and narrow-toothed *Mastodon*, for example, diminish the interval between the *Lophiodon* and the *Elephant*; the *Anthracotherium* and *Hippohyus*, that between *Chæropotamus* and *Hippopotamus*; the *Acerotherium* was a link connecting *Palæotherium* with *Rhinoceros*; the *Hippotherium* linked on *Paloplotherium* with *Equus*." The Hippotherium, though resembling a horse in some respects, was a three-toed animal, the very singular modification of the leg and foot exhibited by the existing horse not having been reached till a much later period.

Mastŏdon (*teat-tooth*).
Deinothērium (*huge beast*).
Anthracotherium (*lignite-beast*).
Hippohȳus (*horse hog*).
Acerothērium (*hornless beast*).
Hippothērium (*horse beast*).

Large Carnivora also have been discovered, as the *Amphicyon*, a forerunner of the Plantigrade family or that to which the Bears belong, and the *Machairodus*, some species of which were as large as a lion, and, from the size and shape of their teeth, at least as powerful and ferocious.

Dr. Falconer and General Cautley made a magnificent collection of strange animals from the Sewalik Hills of India many years ago. Among them was the shell of a tortoise, the curved back of which is 20 feet across, as may be seen in the British Museum; great Crocodiles also occurred, and a large Ostrich, with several Monkeys, some Carnivora, an extinct species of Giraffe and Camel, five extinct species of Elephant, and a very remarkable animal which they called *Sivatherium* (*Siva's beast*); this was as large as a Rhinoceros, had four horns, and probably a proboscis also, thus forming a kind of link between the Ruminantia and the Proboscidea.—(Mantell's *Wonders of Geology*.)

Amphicyŏn (*doubtful dog*). Machairŏdus (*sabre tooth*).

CHAPTER XXIII.

PLIOCENE PERIOD.

THE Pliocene Period is that in which the recent or existing species of shells attain a *plurality*, or amount to more than 50 per cent of all those found fossil.

We have a few small deposits belonging to the Pliocene Period in Suffolk. These are composed of soft marly sands, and of red sand and gravel with banks of shells, and are known to the people of the locality as Crag. Their whole thickness is not much more than 100 feet, and this never in one locality; but they are divisible into the four following groups :—

	Feet.
4. Chillesford and Aldeby beds . . .	20
3. Norwich Crag	20
2. Red Crag	50
1. Coralline Crag	30

Coralline and Red Crags.—These two groups lie side by side of each other, the Red Crag abutting against the Coralline, and sometimes lying in the hollows of it, thus showing the latter to be the older of the two. These deposits are full of fossils, a few of which are figured in the following group.

Echinus Woodwardii and *Temnechinus excavatus* resemble some still living urchins. *Terebratula grandis*

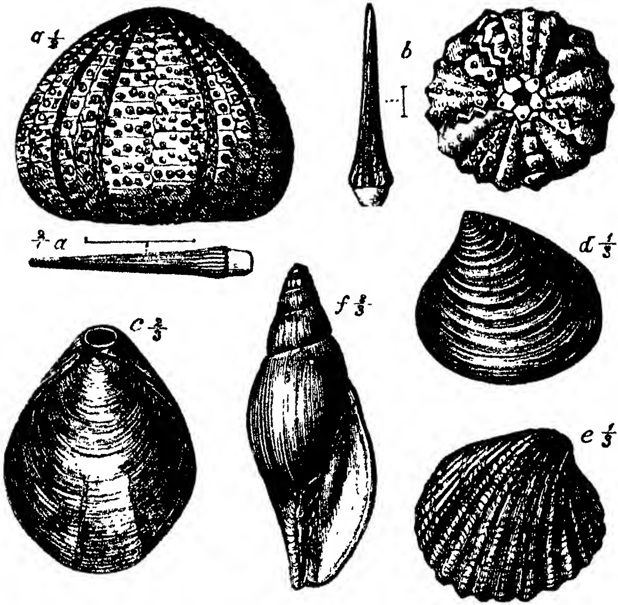

Fig. 72.
Crag Fossils.

a. Echinus Woodwardii.	*d*. Astarte Omalii.
b. Temnechinus excavatus	*e*. Cardita senilis.
c. Terebratula grandis.	*f*. Voluta Lamberti.

is a fine extinct species of the Brachiopoda. *Astarte Omalii* and *Cardita senilis* are extinct species of Lamelli-

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Echīnus (*a sea-urchin*) Woodwardii (*of Woodward*).
Temnechīnus (*cut urchin*) excavatus (*excavated*).
Terebratŭla (*little bore-hole*) grandis (*magnificent*).

branch genera, of which there are many living species; and *Voluta Lamberti*, an extinct species of a well-known living genus of Gasteropods. The two first and the last are found only in the Coralline Crag, but the three others both in that and the Red Crag. Each of these deposits has many species peculiar to itself, as well as many common to the two; the shells of the Red Crag having a rather more northern character than those of the Coralline.

Norwich Crag.—There are in the neighbourhood of Norwich some beds of Crag which contain a mixture of marine, land, and fresh-water shells; most of these are now living, and among them are a few northern forms, such as *Rhynchonella psittacea*, *Astarte borealis*, and *Panopaea Norvegica*; *Littorina littorea*, *Cardium edule*, and *Turritella communis*, are also frequent in these beds, proving their littoral origin. Mr. Prestwich is inclined to believe that they represent the estuarine conditions of the Red Crag, and are not really a newer formation. The Norwich Crag has been also called the Mammaliferous Crag, from the number of mammalian bones which are found in it. Among these are two extinct species of *Elephas*, called *E. antiquus* and *E. meridionalis*, and one species of the extinct genus *Mastodon*, called *Arvernensis*. The bones occur principally, if not exclusively, in the basement stratum of flint nodules and pebbles, which rests immediately

Astarte (*proper name*) Omalii (*of Omalius*).
Cardīta (*heart shell*) senīlis (*aged*).
Volūta (*twisted shell*) Lamberti (*of Lambert*).

on the chalk, and is called the "*Stone Bed*" by Mr. Gunn.

Chillesford and Aldeby Beds.—Returning again to Suffolk, in the neighbourhood of Chillesford, near Aldborough, and of Aldeby near Beccles, there are deposits of yellow sand and clay which spread over the two older Crags and also stretch northward over the area occupied by the Norwich Crag. They contain shells of a more arctic character than any other of the Crags; two-thirds of the species collected by Messrs. Crowfoot and Dowson at Aldeby are characteristic of high latitudes, and among these may be mentioned *Cardium Grœnlandicum*, *Yoldia limatula*, *Lucina borealis*, and *Scalaria Grœnlandica*.

Continental Pliocene.—While these little deposits were being formed in the shallow sea which then spread over a part of the east of England, just as similar deposits may be now forming in the German Ocean, other much larger groups were being deposited in other parts of Europe. Sir C. Lyell refers to this period the beds which form the sub-Apennine hills of Italy, single members of which are 2000 feet thick; and large areas in the east of Europe, especially to the north of the Black Sea, and round the Caspian and Aral Seas, are coloured as Pliocene in the geological maps of Europe.

The beds mentioned on p. 22 as occurring under the eastern base of Mount Etna, and many of the rocks of Sicily, rising to a height of 3000 feet above the sea, also belong to the latter part of this period.

CHAPTER XXIV.

PLEISTOCENE PERIOD.

Since the Pliocene Period is that containing a plurality of existing species, the Pleistocene would be that in which the existing species were in the greatest abundance—above 95 per cent, or even all recent. Sir C. Lyell has, however, abandoned this term for Post-Pliocene; it is here used as an equivalent for Lyell's Post-Tertiary, to include the Glacial and Recent Periods.

Section I.—Glacial Period.

We have already noticed the gradual refrigeration of the climate during the Pliocene period; the further progress of this, and the traces it has left behind, will occupy the present section.

The Forest Bed.—The relation of this bed to the Crags described in the last chapter is not very clear, but it may be safely considered as of later date than the Norwich Crag, and it is seen to underlie the oldest Glacial beds along the Norfolk coast. This Forest Bed consists of a matted mass of roots, twigs, bark, and other remains of forest vegetation, among which the stumps of trees in their position of growth are sometimes seen. Overlying this buried forest is a set of sands, clays, and

lignites, about 10 feet thick, which contain in some places fluviatile shells belonging to recent species. The fossils found in the bed below are remarkable; the trees consist of Scotch fir, Spruce fir, Yew, Sloe, Alder, and Oak; while remains of the Buckbean and Water-Lily have also been found; but with these occur the remains of three kinds of Elephants—*antiquus*, *meridionalis*, and *primigenius* or the Mammoth; two species of *Rhinoceros*—one called *Etruscus*, and the other *leptorhinus*; the *Hippopotamus major*; a large extinct species of Beaver, and also the European Beaver, and several Deer, Bears, and other animals.

This old buried forest and its associated beds have been traced at intervals for a distance of forty miles along the coast, but to the north of Cromer they are replaced by crag-like sands resting on the eroded Chalk, and containing marine shells, among which Tellina solidula (or Balthica) is conspicuous for its first occurrence. These sands were at one time identified with the Norwich Crag, but are now considered by Mr. Searles Wood jun. to be the oldest member of the Glacial Series.

The Glacial Series.—The Sands and Clays above alluded to are covered by a mass of stiff brown clay containing large angular blocks brought from various distant localities, some even from Norway and Sweden (Lyell's *Antiquity of Man*, p. 262). This Lower Boulder Clay appears to thin out both northward and southward, and is overlapped by some curiously contorted loams and silts, often called the "Contorted

Drift." These again are covered by a series of sands and gravels which have received the name of Middle Drift, and are widely spread over the counties of Norfolk, Suffolk, and Essex.

These deposits, however, are concealed from sight over a large part of this area by a greater or less thickness of the Upper Boulder Clay, a stiff blue or grey clay which extends beyond the limits of the Middle Drift into Bucks, Bedford, Cambridge, Rutland, and other Midland counties. A gradual deepening and extension of the glacial sea is thus indicated over England.

The Scotch Boulder-Clay.—In Scotland there occur masses of unstratified clay full of rounded and angular fragments of rock, which are believed by good authorities to be older than the deposits above mentioned, and to have been formed under a great covering of ice, such as exists in Greenland at the present day.

This deposit is called Till, and is evidently the result of the grinding action of the ice as it passed over the surface of the ground, but whether it was accumulated on land or was deposited in water must be considered as a moot question. Its upper portion seems certainly to have been arranged by marine currents, for it shows a rude stratification, and contains numerous lenticular patches of sand, gravel, and loose clay, in which marine shells are occasionally found.

Glaciation of Britain.—Underneath this Till, and in many other parts of the British Islands, the hard rocks are polished and grooved and scratched precisely in the same manner as the rocks from which a glacier

has recently receded. These marks are traceable in some parts over the whole country, from a height of 2000 feet down to the shore, where they pass beneath the sea at low water. It is supposed that at the time of the greatest extension of the ice sheet the British Islands were higher out of the water than they are now, that they were afterwards depressed till the mountain-tops only were visible, and icebergs from the north-east, and from the ends of the British glaciers which then dipped into the sea, floated over the lower lands, grounding in the shallows, and depositing their burdens of mud and stones to form the Boulder clay and stratified Drifts. The land was then re-elevated, and again occupied by ice and glaciers, which, however, became smaller and smaller as the climate ameliorated, and gradually dwindled away.

Later Stratified Drifts.—In many parts of Britain there occur beds of clay, sand, and gravel, more or less regularly stratified, and rising to great heights above the sea. Marine shells have been found in such beds at a height of 1300 feet in Wales; but whether these were deposited after the Upper Boulder clay, or during the great subsidence is difficult to decide.

In Ireland the stratified drifts show three varieties. The first is that of the Limestone gravel, consisting of well-rounded blocks and pebbles of Carboniferous limestone of almost all sizes, interstratified with beds of dark clay or fine sand. The limestone gravel spreads all over the interior, over the Limestone plain, and up on to hills of Granite, Silurian slate, Old Red Sand-

stone or Coal-measures, to heights of 700 feet above it, and 1000 above the sea. The second variety is the marl of Wicklow and Wexford, which is interstratified with beds of sand and gravel, and contains many marine shells. This spreads over the lowlands and up to heights of about 5000 feet above the sea, but is apparently newer than the first-mentioned variety, for near the town of Wicklow the Limestone gravel was seen beneath it in a railway cutting. Marine shells have been found both in these Wexford sands and in the Limestone gravel near Dublin. The third variety consists of beds of sand and gravel made of the waste of the Old Red Sandstone, which in Cork and Waterford often spreads for some distance over the Carboniferous limestone and other rocks.

The upper part of the Limestone gravel of the centre of Ireland is in many places heaped into narrow winding ridges, which are called Eskers. These often look like irregular railway embankments, and run in sinuous lines for 20 or 30 miles, sometimes attaining a height of 100 feet. They often have very steep sides, with only space for a fence or a narrow road on the top. Double and triple lines are formed, sometimes enclosing hollows or flat spaces, with a bog at the bottom, and the large bogs of the centre of Ireland are often more or less surrounded by Eskers. Similar ridges occur in Scotland, where they are called Kames. (For this and other points, see Ramsay's *Phys. Geol. of Great Britain.*)

In the estuary of the Clyde there are certain stratified sands and clays, containing an abundant marine

fauna, which are found to overlie the Boulder clay of that district; their precise age, however, relatively to other stratified drifts, is difficult to determine, but they would seem to be somewhat newer than those just described.

Erratic Blocks.—Besides the Boulder clay and the Stratified drifts, there occur detached blocks of rock scattered loose over the country. These are sometimes rounded and sometimes angular, and of all shapes that it is possible for a natural block to retain. In Scotland blocks of granite and gneiss from the Highlands are found fifty or sixty miles south of where they occur *in situ*. In England blocks of the Cumberland and Westmoreland rocks, some of which are readily identifiable, as is the case with the peculiar granite of Wasdale Crag near Shap, are found over all Lancashire, Cheshire, Shropshire, and Staffordshire, and crossing the lower parts of the Pennine chain are thence scattered over the vale of York. In Ireland blocks of the Leinster granite are found on the hill tops and sides, as well as in the valleys, of the slate country between the granite and the sea. I found one of these blocks above the Devil's Glen in County Wicklow to be 27 feet long, 15 broad, and 11 high; it rested on Cambrian slate at a distance of ten miles from the nearest granite, and at a height of 650 feet above the sea. This is perhaps the largest transported block in the British Islands.

The only way in which the presence of these far-transported blocks can be accounted for, is by referring

them to the action of ice-floes and icebergs; these would contain blocks of rock frozen into them, and as they melted would drop their freight of blocks from time to time on the sea-bottom. The lower hills, which at the time of depression and submergence formed banks or shoals in the sea, would often catch and strand these icebergs, so that the blocks would be left on their summits and sides.

It is to the action of the various eddies and currents in the shallowing seas before the final emergence of the plains, and the flux and reflux of the tides as they flowed in and out of the glens and valleys, which would at one time be bays and harbours, that I believe the Eskers and Kames are to be attributed. It was probably about this time also that the singular terraces were formed which occur round some glens in the north of Scotland and are known as the Parallel Roads of Glenroy. (See *Antiquity of Man*, 4th ed. p. 300.)

Fossils of the Drift.—Shells are by no means abundant in the Glacial Series, and have only been found in a few localities. In the later stratified drifts, however, they occur as above mentioned in Wales, Ireland, and Scotland. Some of these fossil shells are given in Fig. 73; they all belong to existing species, and most of them are now living in British seas; some of them, however, are found only on the northern coasts of Scotland, and others are not found even there, but must be sought on the coasts of Norway, or Greenland, or Spitzbergen. *Pecten Islandicus* is a scallop now confined to Arctic seas; *Astarte elliptica* is one of

those living on the coasts of Scotland. *Fusus Fabricii* is an Arctic species found in the Irish Drifts, while the

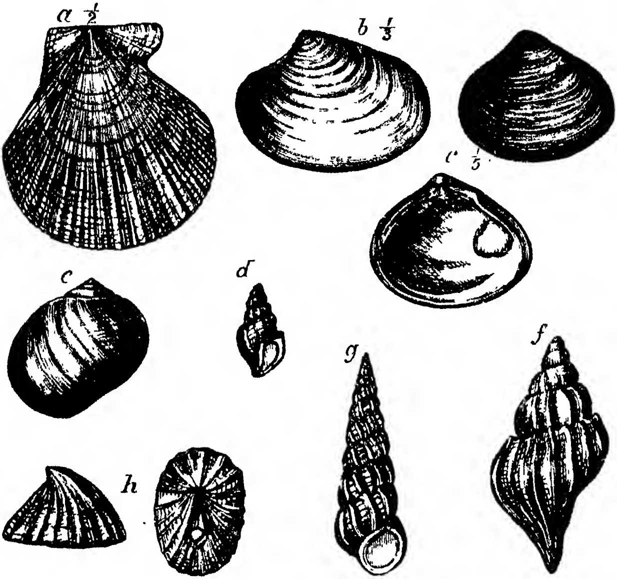


Fig 73

Pleistocene Fossils

a. Pecten Islandicus.
b. Astarte elliptica.
c. Cyrena fluminalis
d. Fusus Fabricii.
e. Natica Grœnlandica.
f. Fusus scalariformis.
g. Scalaria Grœnlandica.
h. Cemoria Noachina.

other four univalve shells are both Arctic and Boreal,

Pecten (*comb-shell*) Islandicus (*of Iceland*).
Astarte (*the Syrian Venus*) elliptica (*elliptic*).
Fusus (*spindle-shell*) Fabricii (*of Fabricius*).
Cyrēna (*proper name*) fluminālis (*living in rivers*).

the latter designation applying to the seas which lie between the Celtic province of our own islands and that of the Arctic Ocean.

Cyrena fluminalis is not a marine shell; it is found in the older river-gravels to be described presently, but does not now live in British rivers, nor indeed anywhere in Europe, being only found in the Nile and other African streams; it indicates therefore a much warmer climate than the other shells.

Foreign Deposits.—It is not only in the British Isles that we have evidences of a cold climate during this period, the plains of Germany and Russia are strewn with great blocks, some of them as large as cottages, derived from the rocks of the Scandinavian Peninsula and Finland. The extreme cold was felt even in Switzerland, where the glaciers spread far beyond their present limits, across the great valley from the Alps to the flanks of the Jura, and down on to the plains of Italy, as far as the vicinity of Turin, where immense moraines derived from them now appear like chains of hills. After this great extension of the glaciers a rather warmer period ensued, followed eventually by a second advance of the glaciers.

Dr. Hooker has lately described the former existence of glaciers on the Libanus in Syria down to a level of 4000 feet below the crest of the chain, which is 10,000 feet high. The cedars of Lebanon grow on the moraine of one of these old glaciers.

The same author showed in his Himmalayan Journals the great former extension of the glaciers on the

south side of the Himmalayahs, huge moraines now existing in the valleys several thousand feet below any of the present glaciers. In North America, also, there are similar evidences of great glaciation, depression, and elevation.

Cause of the Glacial Climate.—Several explanations have been offered to account for this universal prevalence of glacial conditions at a comparatively recent epoch, and three important causes affecting climate have been pointed out. These are changes (1) in the geography of the earth, (2) in the form of the earth's orbit, (3) in the position of the earth's axis.

Changes in the relative position and proportion of sea and land will doubtless materially affect the climate of any place on the surface of the earth, but, as a rule, only in a limited degree and more or less locally.

External influences, however, will exercise a more general effect, and the following brief sketch of an argument which has been elaborately discussed by Mr. J. Croll in his "Climate and Time" may be useful to the beginner, though the details of the subject are more fitted for the advanced student. The earth moves like the other planets, in an ellipse about the sun, which occupies one of the foci; the form, however, of this ellipse is not constant, but changes very slowly, becoming now more circular, now more oval in its outline. If the orbit were a circle, then the sun would be in the centre and the amount of heat received by the earth at each point of the orbit would be the same; but suppose the orbit to be an ellipse of rather

elongated form, then when the earth is at the end nearer to the focus occupied by the sun (in *perihelion* as it is called), the heat received from that orb is considerably greater than when the earth is in *aphelion*, *i.e.* at the end farther from it. Suppose, for example, that, as now, the winter in the Northern hemisphere happens when the earth is in perihelion, then though the northern regions are turned away from the sun, yet the greater proximity of the earth to it tempers the winter's cold; and similarly as the summer takes place when the earth is in aphelion, its heat is mitigated; in the southern hemisphere, on the contrary, both the heat of summer and the cold of winter are augmented. Now, the long cold winter in the latter hemisphere causes a great accumulation of ice and snow, the melting of which absorbs a large portion of the sun's heat and produces dense fog and clouds; these cut off the rays of the sun, and the result is that, in the higher latitudes of the southern regions, summer is actually colder and not hotter than that in the northern hemisphere.

Another change is brought about by a slow motion of the axis of the earth during its revolution round the sun; this *precession* as it is called (for the explanation of which we must refer the student to any manual of astronomy) has the following result; that the axis of the earth at the end of any one annual revolution is not parallel to the position which it occupied at the beginning; it moves slowly on, so that at the end of 21,000 years it is again parallel to its former position. The effect of this is, that if the northern hemisphere

has its winter at any time in perihelion, at the end of 10,500 years, it will have its summer in that position ; thus precession (with other causes) brings about a complete cycle of changes once in every 21,000 years.

As the changes in the form of the earth's orbit are very slow, and quite irrespective of the movement of precession, this latter may at one time intensify, at another time mitigate, the effects of an unusually oval orbit. Again, geographical changes on the earth's surface may coincide with one or both ; and thus these three causes of climatal change, being entirely independent in their action, may severally co-operate with or counteract each other.

Section II. Recent Period.

The Pleistocene Land.—It is not unlikely that at the close of the last elevation referred to at p. 365, the land was at a somewhat higher level than now ; this would have a tendency to unite the British Islands with the Continent, and this union may have been made more complete by the greater extension of the Boulder clay and other Drift deposits forming plains perhaps where we have now the Irish Sea and the German Ocean. The hollows in which those seas now lie may have been formed partly by the erosion of the low lands and partly by the general subsidence of the land. The former continuity of the land is rendered probable by its having been all inhabited by the same large land animals, its subsequent depression by the fact that peat-bogs with

the roots of large trees in the position of growth, exactly like the peat-bogs now growing on the land, stretch beneath the sea, and are exposed at low water of spring tides at numerous places round all the British Islands and the opposite continental coasts.

The bones of the extinct land animals are found sometimes in the marls of old lakes, now dry and generally buried under peat-bogs, in the river gravels whether of the high or low levels, and in caves, where they occur in clay under a covering of stalagmite, or sometimes in heaps of broken bones without any such cover. In some cases these caves can be shown to have been used for long periods as dens by the extinct hyænas or bears, the bones of the larger animals having been carried in piecemeal and gnawed and broken there. In others the bones and the clay were swept into the caves by the subterranean rivers and floods which then traversed them, as streams of water now traverse many of the lower caves which are found in all limestone countries. The old bone caves are now dry, because the adjacent rivers have cut their valleys so deep that the drainage of the country runs at a lower level, and therefore no longer gets access to these caves.

The most remarkable of the land animals that lived during this Pleistocene period, and have now become extinct, are the following:—*Elephas primigenius,* the woolly elephant or mammoth; *Rhinoceros tichorhinus* or woolly Rhinoceros, and two other species in the cave

Elephas (*elephant*) primigenius (*first-born*).
Rhinocĕros (*nose-horn*) tichorhīnus (*wall nose*).

deposits; *Hippopotamus major*, *Bos primigenius*, the large deer called *Megaceros Hibernicus* or Irish elk; *Ursus spelæus*, *Hyæna spelæa*, *Felis spelæa*. To these may be added the *Cervus tarandus* or Reindeer, and the *Bison Europæus* or Aurochs, which, though extinct in the British islands, still exist in the northern parts of Europe.

Existence of Man during the Pleistocene Period. - In many of the caves which contained the bones of the extinct animals, human bones and implements have been also found. Geologists were for a long time restrained by a natural reluctance to assert that man was contemporaneous with the extinct animals, without the clearest proof of the fact. It was felt that as man is a digging animal, early races of men might have buried their dead beneath the bones of the animals which they had themselves dug from their original resting-places. Many persons, however, were nevertheless convinced that the human and animal bones were of contemporaneous origin. This is believed to have been the opinion of the late Rev. Mr. MacEnery, a Roman Catholic clergyman of Torquay, who was the companion of Dr. Buckland in the examination of the Kent's Hole cave. It was the decided opinion of Dr. Schmerling, of Liege, who found in the caves of

Hippopotamus (*river-horse*) major (*greater*).
Megacĕros (*big-horn*) Hibernicus (*Irish*).
Ursus (*bear*) spelæus (*cavern*). Hyæna (*wild hog*) spelæa (*cavern*).
Felis (*cat*) spelæa (*cavern, probably only var. of common lion*).
Cervus (*a deer*) tarandus (*Lat. name for reindeer*).

that province bones of extinct animals and human skulls and implements, in narrow tortuous recesses, to which he could only penetrate by being let down by a rope, and crawling on all fours along wet passages.

These ossiferous caverns are numerous in the limestone country traversed by the Meuse and its tributaries, and many of them were the channels of streams before the valleys of those rivers were cut to their present depth, bones being brought in by the floods of those streams. The teeth of the Mammoth, and human skulls, and the other bones of both man and beasts, occur here and there, equally scattered and detached from the rest of their skeletons, as they would be by the capricious distribution of casual floods; and they are all in a similar state of preservation.—(Lyell's *Antiquity of Man*, chap. iv.)

M. Lartet has lately described an ancient tomb near Aurignac, in the south of France, before which funeral feasts had been held, and among the ashes were found flint implements, together with the *burnt* bones belonging to most of the extinct animals mentioned above, in such a state as to show they had been cooked by man.

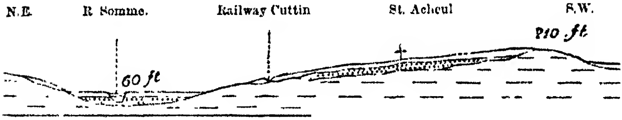
River Gravels.—The flint implements above mentioned are found in great abundance in the lacustrine deposits and river gravels of England and France. These beds occur either in the bottoms of the valleys, within or but little above the reach of possible river floods at the present time, or at various heights on the flanks of the valleys. The former are Mr. Prestwich's "Low Level gravels," and the latter his "High Level

gravels," which are sometimes at a height of 100 or 200 feet above the rivers, and far out of reach, therefore, of any possible floods. These must have been deposited by the rivers when the valleys were much shallower than at present, or before the rivers had excavated the valleys to their present depth.

The flint implements are not all of the same shape and manufacture, some being very much older than others, and only roughly chipped into the form of adzes or hatchets; to designate these first rude attempts at fashioning flints into useful instruments, and the earlier part of the great "stone age" which they represent, Sir John Lubbock has proposed the name of *Palæolithic*, while to the polished or neatly trimmed implements of later date, like those used by many savage races at the present day, he has given the name of *Neolithic*. M. Boucher de Perthes, of Abbeville, was the first to figure and describe these implements, Messrs. Prestwich and John Evans subsequently taking up and working out the inquiry both in France and England.

In France there is no Boulder clay or other far-travelled drift—the blocks and pebbles in the lower part of each river-basin being derived from rocks somewhere *in situ* in its upper part. The gravels are all of fluviatile origin, containing no marine shells except in the parts near the sea, where the tide once flowed up the valleys. These gravels occur in detached patches at various heights above the present level of the rivers, and, where Chalk is the subjacent rock, they consist chiefly of Chalk-flints, often much rounded

and stained with ferruginous colours. Angular blocks of other rocks also occur occasionally in the sands and gravels, but always of rocks that are somewhere traversed by the rivers. The flint implements are scattered in the lower part of the flint gravels, often at a depth of 20 or 25 feet from the surface. One of the places where they occur is at the village of St. Acheul, near Amiens, in the valley of the river Somme, as shown in the following figure. Many hundred flint weapons, spear-heads, hatchets, ice-chisels, and digging implements, have been found at this locality.



Section across the valley of the Somme, near Amiens, from Mr. Prestwich.

The lower part with horizontal strokes is the Chalk. The dotted parts are the gravels. The undotted parts above these are fine brick-earth on the slopes, and silt and peat in the bottom of the valley.

The explanation offered by Mr. Prestwich as to the occurrence of these gravels, is, that they were deposited in the bed of the river when its channel ran along the places where they are now found. Since that time the whole length of the valley has been deepened by the action of the river, this excavation having, near Amiens, removed a mass of chalk more than a mile in width, with a maximum depth of 100 feet, and a proportionate mass through the rest of the valley. It seems

to me that the whole channel of the river would at one time have been on the higher part of the slope, between the part marked 210 *ft.* and *St. Acheul*, that it then began to cut into and remove the chalk on the N.E., gradually deepening its channel in that direction till it arrived at its present bed, always leaving the gravel of its former bed, and depositing fresh gravel in the new one as it worked its way down the slope.

Fragments of the hard parts of the bones of the Mammoth and its contemporaries are found in these gravels, proving the climate to have been very much colder than at the present day. The tribes of savage men then living in these countries, like those of the northern parts of America and Asia at the present day, would have favourite spots where, during the winter, they would chip holes in the ice, in order to spear the fish and other animals that came to such apertures to breathe, and would lose many of their weapons and implements either through these holes or from their canoes in the summer. These would be carried down by the streams, and buried in the sand and gravel in the bed of the river. The cutting power of the rivers would be much greater then, in consequence of the swiftness of their currents, and it would be aided by the floods when the snows melted, and by the ice which would be brought down by those floods.

This cutting power would gradually diminish as the valleys were deepened and the strength of the currents lessened. Near their mouths the rivers have now long ceased to exert any erosive action, and have

been in process of being silted up and bogged up; but if the country were to receive an elevation of 50 feet, the rivers would resume somewhat of their ancient force, and again set to work to deepen the valleys. One such elevation of 30 feet has probably occurred since the deposition of some of the gravels, evidence of it having been observed by Mr. Prestwich on the coast. It is impossible to arrive at any conclusions as to the exact number of centuries that have elapsed since the rivers ran at their former high levels, but we may feel assured that they have been very many more than the hitherto received chronology admitted.

Foreign Beds and Fossils.—Throughout the continent of Europe we find evidences of the same fauna which inhabited the British Isles in Pleistocene times, and in many parts of the world the remains of other extinct animals are found under similar circumstances; the following pages contain some of the more striking facts connected with these discoveries.

Europe.—The late Dr. Falconer's explorations of the caves in Sicily show us that some of them contained immense accumulations of the bones of *Hippopotami*, to such an extent that ship-loads of them had been exported to be made into lamp-black, mingled with which were remains of *Elephas antiquus*, *Hyæna spelæa* a cave Lion, and extinct Deer and other animals, matted together by stalagmite. There were also siliceous implements and other proofs of the existence of man, such as burnt wood, etc., together with land and sea shells of species that still live in the district.

Dr. Falconer also described at the meeting of the British Association at Cambridge, in 1862, the fossil bones procured by Captain Spratt, R.N., from the caves in Malta, as proving the former existence of a pigmy species of Elephant not much larger than a calf. He calls it *Elephas* (*Loxodon*) *Melitensis*. From its analogy to the African Elephant and other facts, Dr. Falconer believes that Malta was connected with Africa at the time that this small Elephant lived there.

Siberia.—The ground beneath the plains of Siberia abounds to such an extent with the tusks of the Mammoth *Elephas primigenius*, that the fossil ivory is an important article of commerce, and was at one time an imperial monopoly. It appears from Sir R. I. Murchison's "Geology of Russia and the Ural," that near the Sea of Azof there is a clay 50 feet thick full of Mammoth bones, and that alluvial deposits of clay and mud spread largely over the northern part of Siberia, especially in the neighbourhood of the great rivers, and that the bones become more numerous and better preserved the farther the rivers are followed towards their mouths, until at length whole skeletons and even carcases are found entire. The animals may have inhabited the forests on the flanks of the Ural and Altai mountains during the winter, and in summer perhaps migrated north in great herds, many of them perishing in crossing the rivers, and thus their carcases having been floated down and buried in mud were frozen into it in the winter. A gradual elevation of the land seems also to have been going on, so

that the coast was extended farther towards the north, and the carcases thus drifted to greater distances in that direction, while the former alluvial muds were raised into dry land above the reach of the river floods.

When once frozen in mud or thick ice, the carcases of the animals might endure for almost any length of time. In the year 1799 a Tangusian fisherman observed a strange mass projecting from an ice-bank near the mouth of one of the rivers, which thawed out, in succeeding summers, till it disclosed the entire carcase of a Mammoth. In 1806 a Mr. Adams went to examine this animal, and found the remains of the carcase that had been left by the wild beasts, and removed all he could of it to St. Petersburg, where it still exists. The skin was extremely thick and heavy, and was clothed with three kinds of hair—stiff black bristles a foot or more in length, coarse flexible hair of a reddish-brown colour, and coarse reddish-brown wool, which grew among the roots of the long hair. This thick clothing showed that the animal was adapted to a cold climate. The word Mammoth is of Siberian origin, and means Earth Beast.

In 1771 the carcase of a *Rhinoceros tichorhinus* was dug up out of the frozen soil near Vilhorii on the banks of the Wilaji river, a tributary of the Lena, and was in like manner found to be covered with long hair and wool, as recorded by Pallas in his *Voyages dans l'Asie Septentrionale*.

The Liakhow Islands, off the north coast of Asia,

consist of sand and ice, with such enormous quantities of Mammoth bones, that they seem to form the chief substance of the islands; they are mingled with the bones of the Rhinoceros, and with the bones and horns of deer somewhat different from the existing reindeer. In 1821 as much as 20,000 lbs. weight of fossil ivory was procured from the island of New Siberia, some of the tusks weighing 480 lbs.

North America.—In Escholtz Bay, at the head of Kotzebue Sound, in North America, cliffs composed of or fronted with ice were found to be covered with boggy soil full of bones and skulls of Elephants and other animals, with quantities of hair, and all so fresh that the whole deposit had a charnel-house smell. The bones identified belonged to the Mammoth, the fossil Horse, the Moose Deer, the fossil Reindeer, the fossil Musk Ox, and another Ox larger than any living one, the Arctic fossil Bison, and the heavy-horned fossil Bison.—(Richardson's *Polar Regions.*)

The Mammoth remains are found in North America, far to the south of those latitudes, but as we come down towards the Gulf of Mexico, they give place to another species called by Dr. Falconer *Elephas Columbi.*

In the central parts of North America, never north of latitude 51°, there have been found in lacustrine and alluvial deposits abundant remains of another great proboscidean animal belonging to the extinct genus Mastodon. This American species is called *Mastodon Ohioticus;* it is the one of which an entire skeleton is

set up in the Palæontological gallery of the British Museum.

South America.—Another large group of extinct animals have left remains in South America, both in the caverns in Brazil, and in widely-spread deposits of mud and sand beneath the plains known as the Pampas.

MM. Lund and Clausen examined as many as 800 caves in Brazil, and found the remains of 101 species of animals, many of them of extinct species and genera. In six of these caverns they found human remains mingled with the bones of the extinct animals, and apparently contemporaneous with them ; stone hatchets were also obtained in the same place.

Among the South American fossils it is curious to find the remains of a horse rather abundant, though no such animal existed in South America when it was invaded by the Spaniards. There was a Mastodon also, which is called *Mastodon Andium*, and is peculiar to South America.

The most remarkable of these fossil animals, however, were large species of genera, of which the living representatives are now almost restricted to the South American continent. These genera are grouped into an order called Edentata (*toothless*), from their having no front teeth. The Sloth (*Bradypus*), the Armadillo (*Dasypus*), and the Anteater (*Myrmecophagus*), are the chief of these ; and the whole order, with the exception of the African and Asiatic Pangolin (*Manis*) and the African *Orycteropus*, is confined to South America.

The extinct genera include the *Megatherium*, an animal eighteen feet long, and the *Mylodon*, whose skeleton is eleven feet in length, which were allied to the Sloths, and, like them, lived principally on the leaves of trees, which their huge fore-paws, armed with great recurved claws, enabled them to root up and throw down, while the smaller sloths of the present day have to climb and live among the branches.

The *Glyptodon* was more nearly allied to the Armadillos, and, like them, covered with a coat of mail, which, however, was not banded, but like a tessellated pavement. The one in the Museum of the College of Surgeons, London, measures nine feet in length.

There was also a large extinct Llama called *Macrauchenia*, and other animals more or less closely allied to those now living in South America. It is in fact a general law, that the limitation of particular *genera* to certain provinces began before the introduction of existing *species*, and that the present geographical distribution of animals results from a preceding distribution in early Pleistocene times.

Australia.—Similar discoveries have been made in Australia, where bones have been found, in the caves and superficial deposits, belonging to animals of the Marsupial order, which at the present day is entirely confined to Australasia, with the single exception of the American Opossums or the genus *Didelphys*.

Megathērium (*great beast*). Mylòdon (*millstone tooth*).
Glyptŏdon (*carved tooth*). Macrauchēnia (*long neck*).

The fossil Kangaroos (*Macropus Atlas* and *M. Titan*) must have been nearly as large as a horse. The skull of the great *Diprotodon*, an animal intermediate between the Kangaroos and the Wombats, is three feet across. Other extinct species were allied to the two called the Native Wolf (*Thylacinus cynocephalus*) and Native Devil (*Dasyurus ursinus*) still lingering in Tasmania, but not known to exist elsewhere even in Australasia; while another carnivorous Marsupial, called by Owen *Thylacoleo carnifex*, rivalled the Lion in size, and perhaps surpassed him in voracity.

New Zealand.—When New Zealand was discovered by Cook there were no Mammals in it larger than rats, so that Birds were the largest land creatures the Maori were acquainted with. Among these was a singular genus called the *Apteryx*, allied to the Ostrich and the Emeu, but not larger than our domestic poultry. Bones of a gigantic bird called *Dinornis* have since been discovered there, also allied to the *Apteryx*, but larger than an ostrich, as well as those of other and smaller species. The *Dinornis* is known to the natives as the Moa, and was certainly exterminated by their ancestors, even if it be actually extinct; the country, however, has been pretty well explored, and none have been seen.

Macropus (*long foot.*)
Diprotodon (*two front teeth*).
Thylacīnus (*pouch-beast*) cynocephălus (*dog-headed*).
Dasyurus (*hairy tail*) ursīnus (*bear-like*).
Thylacoleo (*pouch-lion*) carnifex (*a butcher*).
Dinornis (*huge bird*). Æpyornis (*tall bird*).

Indian Ocean.—In Madagascar huge eggs have been found, proving the former existence of a gigantic bird, to which the name of *Æpyornis* has been given.

When the Mauritius was first visited by the Dutch, a large bird called the Dodo was found there, and the islands of Bourbon and Rodriguez were inhabited by another called the Solitaire. These were exterminated soon after the discovery of the islands.

CONCLUSION.

The geological history of the Earth thus closes with the appearance of Man exterminating races of animals, just as preceding races had been exterminated by other animals than Man.

If this history were to be made complete, it should include an account of the aqueous rocks that were deposited, the igneous rocks that were intruded or ejected, the preceding aqueous rocks that were altered or destroyed, the animals and plants that made their appearance, and those that disappeared, during each period of the history, and for every large division of the globe. It is obvious that the little sketch now given affords but a feeble outline of such a history.

The account of the Pleistocene period should properly include that of existing Volcanoes, Earthquakes, Coral reefs, and the other actions now proceeding, which have been given in Chapters II., IV., V., VI., and VII. These chapters were detached from their proper place, and given in the first instance in order that we might understand the nature of the operations now going on, and thus learn how to read the history of the past. Geologists were, before the appearance of Sir C. Lyell's *Principles*, mostly led away, for want of this knowledge,

into mere speculations as to what might have produced the Earth's crust, instead of patiently studying the actions which were now operating in that production. Hence arose such notions as that Granite was necessarily the most ancient of all rocks, and that after the formation of Granite came that of Gneiss, and then that of Mica-schist, then of Clay-slate. The Granite districts of Devon and Cornwall were conceived then to be the oldest rocks of England, and the slates and semi-crystalline rocks that rest upon the Granite to be next in age. But some of the rocks which rest upon the Granite of Dartmoor are now proved to belong to the Carboniferous Period, and it is clear that the Granite has come up in a molten condition and penetrated these rocks, and therefore must be newer than they are, for it could not have penetrated them if they had not been there. We learn therefore that Granite may be intruded into rocks of any age.

Again, we now know that any rocks of suitable character, no matter of what age, may be altered into Gneiss, or Mica-schist, or Clay-slate; but the term "Transition" was at one time used to designate an imaginary period between that of the formation of the so-called crystalline rocks and the others. Part of the same prejudice still lingers among Geologists, and induces them to regard the present time as distinct from the Tertiary Epoch, and to introduce such terms as Post-tertiary or Quaternary.

It is true that the spread of a cold climate seems to have been very general over the world during part

of the Pleistocene period (though probably the glacial epochs in the northern and southern hemispheres may not have been synchronous), and to have formed a marked exception to the meteorological conditions that had previously prevailed. During former periods the climate of the whole earth seems to have been more genial and more equable than it is now. The change, however, seems to have been a gradual one, both in its in-coming and its out-going, and its probable causes have already been pointed out. We do not find here or elsewhere in the history of the Earth any evidence of an abrupt termination of one order of things and a sudden introduction of another. Few, and scanty, and broken, as are our records of the past, they contain far more evidence of the slow, and gradual, and continuous action of the natural forces, than of rapid, or capricious, or intermittent change. The present day is linked indissolubly with all past time, and that which we see around us is the result of that which has been before.

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THE END

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